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Barley (*Hordeum vulgare* L.) Competition: Effects on Rapeseed/Canola (*Brassica campestris* L. and *B. napus* L.) Growth and Yield

by

Elizabeth Ann de St. Remy ©

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
OF Doctor of Philosophy
IN
WEED SCIENCE

DEPARTMENT OF PLANT SCIENCE

EDMONTON, ALBERTA

Fall, 1991

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THE UNIVERSITY OF ALBERTA

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The undersigned certify that they have read, and recommended to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled **Barley (*Hordeum vulgare* L.) Competition: Effects on Rapeseed/Canola (*Brassica campestris* L. and *B. napus* L.) Growth and Yield** submitted by Elizabeth Ann de St. Remy in partial fulfilment of the requirements of the degree of Doctor of Philosophy in Weed Science.

Supervisor

Gary R. Stringam

Mark R.T. Dale

Date 23 Sept, 1991

ABSTRACT

Barley frequently becomes a problem weed in central Alberta when rapeseed/canola follows a barley grain crop in rotation. Experiments on crop genotype and density, weed density, relative time of weed emergence and time of weed removal were used to examine the rapeseed/canola (crop) - barley (weed) interaction.

Brassica cultivars/lines with high weed-free seed yields usually maintained higher seed yields when barley was present. Under weedy conditions, the *Brassica* groups ranked by yield, as a percent of the weed-free value, were: *Brassica juncea* > *B. campestris* > hybrid *B. napus* > triazine-tolerant *B. napus* = triazine-tolerant *B. napus* hybrid. High yielding cultivars/lines were early-flowering, of medium height, and produced intermediate amounts of vegetative material.

No optimum seeding density for canola (*B. campestris* cv Tobin, *B. napus* cv Westar) grown under weedy conditions was identified. Canola branching and pod numbers were reduced when barley was present, which resulted in lower seed yields.

Canola seed yield declined as barley density increased. At barley densities below 50 plants/m^2, there was a 0.5% yield loss for each barley plant present. Yield relationships were used to develop economic thresholds for chemical weed control. Considering the value of barley grain, post-emergence herbicide treatment for barley control could not be rationalized until there were 57 and 79 barley plants/m^2 in Tobin and Westar canola, respectively.

Barley emerging at different times relative to the crop reduced canola seed yield differentially. Yield loss ranged from 7 to 16 g/m^2 for each day barley emerged before the crop. Reduced canola dry matter production, in the presence of barley which was reflected in reduced pod numbers, and seed yield. Post-emergence herbicide application, considering the value of the barley grain, would be cost-effective if a moderate density of barley (62 plants/m^2) emerged between nine days before and eight days after the crop.

Canola seed yield reduction was proportional to the time barley remained in the crop. Mean reduction in seed yield was 1.3 g/m^2/day. This yield loss was attributable to lower numbers of pods per plant and seeds per pod.

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GENERAL INTRODUCTION

Weeds have been a problem in crop production from the period when man ceased to be a 'hunter/gatherer' and began to cultivate plants. In biblical times, thorns and thistles were sent to plague Adam and Eve (Genesis 3: 18) and man accused his enemy of sowing tares in his crops (Matthew 13: 25). However, man can also sow the seeds of his 'agricultural discontent' as a species that is sown for seed production in one year can often become a weed in the following years.

This situation can be observed in central Alberta where rapeseed/canola (*Brassica campestris* L. or *B. napus* L.) generally follows barley (*Hordeum vulgare* L.) in the crop rotation scheme. Shattering of barley seed while the crop is standing or still in the swath, or poor combine adjustment can result in serious barley infestations in the next crop-year. Until the introduction of such products as POAST® (sethoxydim)[1] and FUSILADE® (fluazifop-butyl)[2] in the early 1980's, producers could only rely on cultural control measures, such as tillage and efficient harvesting procedures, to limit volunteer barley growth in canola crops.

Today, herbicides are routinely used by the farming community to control barley in canola. Little information is available to justify the use of chemical control measures under all circumstances. An understanding of the damage to canola yield caused by barley is indispensable if maximum benefits from weed control are to be obtained. A knowledge of the interaction of canola and barley is important not only to select appropriate chemical control measures but also to combine them with cultural or mechanical control measures which might reduce the overall cost to the producer and the environment.

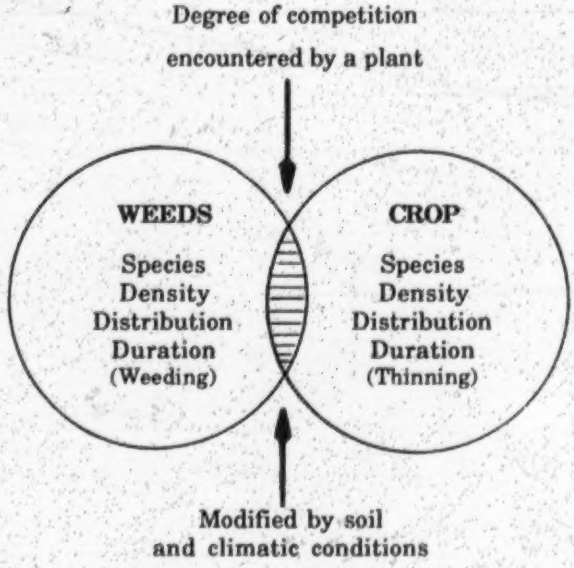
In the field, crop and weed plants live under the same conditions. Like customers of a bank, there is a set limit as to how much credit is available in the 'moisture', 'nutrient', 'light' and 'space' accounts. In most cases, one or more of these 'accounts' are not sufficient to assure the best possible development even of the crop alone. Competition between the crop and weed during the growing season is multi-factored and not very obvious to the casual observer. Final yield, which is a culmination of these processes, is the tangible result with which producers can identify.

Pavlychenko (1949) stated that weed problems were complicated by two factors. The first was the ability of many weeds to thrive and compete severely with crops under adverse condition. The second was the "appalling ignorance, on the part of many crop growers, concerning the biological powers of the crop they want to grow and the weeds they wish to destroy". Schematically the most important factors determining the degree of competition encountered by plants can be summarized as follows (after Bleasdale, 1960):

---

[1] (2 -(1-ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one

[2] (±)-2-[4[[5-(trifluoromethyl)-2-pyridinyl]oxy]phenoxy]propanoic acid


Degree of competition
encountered by a plant
WEEDS
Species
Density
Distribution
Duration
(Weeding)
CROP
Species
Density
Distribution
Duration
(Thinning)
Modified by soil
and climatic conditions

The overall objective of this present project was to examine some 'biological powers' of the canola crop and the weed, 'volunteer' barley. Two aspects of the crop which are determined largely by the producer were studied; 1/ crop genotype and 2/ crop density.

Some rice (Smith, 1974) and sorghum (McWhorter and Hartwig, 1972) cultivars have been identified as being more competitive with weeds than others. No information has been available which conclusively shows whether *B. campestris* or *B. napus* is the most competitive canola species under central Alberta conditions, let alone cultivar differences between the two groups. No one has attempted to identify botanical properties associated with canola yield when it is grown in the presence of barley.

The effect of genotype on the competitive process is not limited to *B. napus* and *B. campestris* alone. The incorporation of triazine-resistance into canola is known to reduce vigour under pure stand conditions (Gressel and Ben-Sinai, 1985). Triazine-resistant canola growth in the presence of barley, and the reduction in yield which may occur, has not been well documented in western Canada. Since SENCOR® (metribuzin)[3] does not control barley, the competitive ability of the herbicide-tolerant crop is an important consideration in choosing a triazine-tolerant canola variety. Increased vigour and yield have been demonstrated when canola hybrids and triazine-tolerant canola hybrids are produced in hand crosses (Sernyk and Stefansson, 1983; Grant and Beversdorf, 1985b). Whether heterosis translates into competitiveness with barley has not been shown. *B. juncea* is a more drought-tolerant brown or yellow-seeded *Brassica*, currently grown under contract for processed mustard. Plant breeders have recently identified low glucosinolate, low erucic acid types which will enable the development of more drought tolerant, warmer season canola-type varieties (Downey, 1983; Love *et al.*, 1990). The ability of this material to compete with weeds is unknown.

---

[3] 4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4*H*)-one

Seeding crops at an optimum rate is known to make cereals more competitive with weeds (Meed *et al.*, 1985). Optimum seeding rates have been identified for weed-free canola (Kondra, 1975), yet there is no information indicating whether they are the best rates for weedy situations.

As barley was the only weed used in this project, weed species was not a factor to be considered in the competitive stresses imposed on the crop. However, 1/ barley density, 2/ the relative time of barley emergence, and 3/ duration of barley competition were examined.

Weed density is the factor which has received the most attention by researchers (Zimdahl, 1980 p. 21). In general, final seed yield is the only growth parameter discussed as it is critical in determining the cost-effectiveness of weed control. Little information exists on how barley affects the production of canola dry matter throughout the growing season or whether the presence of barley alters the partitioning of dry matter into seed yield.

The time at which a weed emerges in relation to a crop affects the competitiveness of both the crop and the weed (Peters and Wilson, 1983; O'Donovan *et al.*, 1985). No one has documented how the time of barley emergence in canola affects development of the crop and the weed or whether there are specific periods during canola yield development that are more susceptible to the stress imposed by the presence of barley in the crop.

Timing of weed control is almost as important as the actual removal of the weed from the crop. The length of time barley can remain in a canola crop before yield loss occurs has not been identified. The development of canola yield following the removal of barley at different intervals in the growing season has also not been documented.

Knowledge of these five factors which contribute to the degree of competition encountered by an individual gives the producer the essential tools to make sound management decisions with regard to canola production when volunteer barley is present or has the potential to be present. The selection of a more competitive canola variety combined with an optimum seeding rate for weedy conditions is a cultural method that can be applied easily. Relying on the crop for weed control is another cultural control method that can be utilized if one knows the yield potential of canola in situations where weeds emerge late or early with respect to the crop. The use or non-use of chemical control methods by farmers frequently hinges on the relationship between barley density and expected canola yield loss and the market value of the 'weed'. If chemical control is justified, the best results can be obtained by knowing whether, and the appropriate time, to apply the herbicide.

LITERATURE REVIEW

1.0 Terminology

The terms interference and competition have both been used to define the interaction between neighbouring plants. Interference is defined as "the act of meddling in or hampering an activity or process" (Webster's Third New International Dictionary, 1976). Harper (1977) stated that "the presence of a plant changes the environment of its neighbours and may alter their growth rate and form". These changes in the environment brought about by the proximity of neighbours constitute interference. No inference is made about the mechanism of this interference. Neighbours may alter the environment not only by the use of limited resources but also by the production of toxins. Harper's definition of interference (1977) encompasses both competition in the strict sense defined as "the act or action of seeking to gain what another is seeking to gain at the same time and usually under or as if under fair or equitable rules and circumstances" (Webster's Third New International Dictionary, 1976) as well as allelopathy. Under natural conditions, these two phenomena are difficult to separate.

Grime (1977) suggests the term competition should be used "in relation to its mechanism rather then its effects". He defines competition as "the tendency of neighbouring plants to utilize the same quantum of light, ion of mineral nutrient, molecule of water, or volume of space". Competition in this mechanistic sense is a term that has been used generally in agricultural research and plays a much larger role in interference than allelopathy (Glauninger and Holzner, 1982). Therefore, the term competition will be used throughout this review.

Inter-specific competition was defined by Radosevich and Holt (1984 p. 97) as "an adverse interaction between two different species" while intra-specific competition was defined as "a negative interaction between plants of the same species". Both types of competition are likely to occur in a weed-crop situation. Even within a crop, breeders have recognized that variety comparisons can be affected by both intra- and inter-varietal competition (Kempton, 1982).

2.0 Crop Factors Involved in the Weed-Crop Competition Process

2.1 Crop Genotype

2.1.1 Competitive Ability of Different Crop Genotypes

Haldane said in his book, *The Causes of Evolution*: "The fitness of plants in the Darwinian sense must be tested with plants grown in competition" (Sakai, 1961). Implied in this statement is that plants have differences in competitive ability that can be inherited. In the case of domesticated plants one might ask: Is the competitive ability associated with botanical characteristics? Is there a relationship between competitive ability and tolerance of different crop genotypes to weeds?

Differences in competitive ability of various crop genera with weeds have been well established (Dew, 1972; Dew and Keys, 1976; Pavlychenko and Harrington, 1934). Information on weed tolerance of crop species within a genus and between cultivars within one species is more limited. Physiological factors such as tillering capacity and plant height relate to genetic control and the role of intraspecific competition in the evolution of the cultivated species (Kawano *et al.*, 1974).

Inheritance of competitive ability has been tested by the traditional quantitative genetics method of looking at variation in progeny and comparing it to parental material or a standard variety. Experiments with rice (*Oryza sativa* L.) have indicated that traits contributing to competitive ability are controlled by genes that are inherited following Mendelian principles. However, other genes involved in the modification of their expression contribute to a very low heritability (Sakai, 1961). Clearly, competitive ability, like yield, is a complex multi-gene phenomenon (Wallace *et al.*, 1972).

In any given environment, different genotypes may have different yielding abilities, or show different degrees of fitness. This fitness is tested when plants are grown under competitive conditions in a mixture (Sandfaer, 1970).

Can specific botanical traits that confer tolerance to inter- and intra-specific competition be identified? Sakai (1955) could not correlate botanical properties like plant height, maturity, seed size, growing habit or grain yield with the competitive ability of 12 barley (*Hordeum vulgare* L.) varieties. The failure to correlate such characteristics may lie in experimental methodology. Jennings and Aquino (1968) stated that the inability to relate plant characteristics to competitive ability occurs when observations are made at inappropriate growth stages.

Intra-specific competitive ability of 25 rice varieties and lines was examined by comparing pure stand yields with the yield of each plant type grown in a mixture with a standard variety. In all cases the rice mixture yield was lower than the pure stand yield. Plant height, plant weight in early vegetative growth and a long growth duration were correlated with competitive ability. There was no correlation between rice tillering and competitive ability (Kawano *et al.*, 1974).

It is apparent that the association of botanical characteristics with competitive ability varies within genera. Vegetative vigour and plant height are characteristics for which a breeder can select. Kawano *et al.* (1974) suggested that breeding for yield, by selecting short-statured plants with early maturity to optimize yield per day, had been at the expense of competitive ability.

Rice lines competing with weeds had a similar response to rice lines grown in a mixture (Kawano *et al.*, 1974). Their observations suggest that intra- and inter-specific competitive ability are controlled in the same manner. In this case, the taller rice lines that had vigorous early growth were more competitive.

Semi-dwarf wheat (*Triticum aestivum* L.) cultivars have been found less tolerant of green foxtail (*Setaria viridis* L.) competition than standard-height cultivars (Blackshaw *et al.*, 1981). Wicks *et al.* (1986) and Challaiah *et al.* (1986) reported that winter wheat cultivars that were good at suppressing weed growth had high grain yields and were generally tall plants.

Differences in the competitive ability of sorghum (*Sorghum bicolor* (L.) Moench.) cultivars were observed by Burnside and Wicks (1972) and Guneyli *et al.* (1969). Sorghum competitiveness was associated with rapid seed germination and emergence as well as with rapid shoot and root growth during the early stages of development.

Forcella (1987a) compared the tolerance to weed competition of two near-isogenic lines of tall fescue (*Festuca arundinacea* Schreb.) that differed in leaf area expansion rates. The high leaf area expansion genotype suppressed velvetleaf (*Abutilon theophrasti* Medik.) growth by 14 to 24% and produced more dry matter than the low leaf area expansion line when grown in a weedy mixture.

Crop maturity has some bearing on the competitiveness of crops. Late maturing, tall soybean (*Glycine max* (L.) Merr.) varieties appeared to be more competitive with johnsongrass (*Sorghum halepense* (L.) Pers.) and cocklebur (*Xanthium strumarium* L.) than early, short cultivars (McWhorter and Hartwig, 1972). Rose *et al.* (1984) reported similar observations. After field screening 280 soybean cultivars for competitiveness, they found that competitive ability was greater as the maturity rating increased. Competitive varieties emerged quickly and had rapid canopy development.

Corn (*Zea mays* L.) yield loss due to yellow foxtail (*Setaria glauca* (L.) Beauv.) competition was greater in later maturing hybrids (Staniforth, 1961). The author suggested that the early-maturing hybrid may have passed a critical period of growth before maximum foxtail competition occurred. While late maturing corn hybrid yield was affected most by foxtail competition, the cultivars also had the highest yield potential under weed-free conditions of all the corn hybrids tested. This illustrates the importance of choosing corn hybrids, and no doubt other crop cultivars, that are adapted to particular field conditions.

To generalize: a competitive crop plant is likely to be a long season cultivar that emerges quickly and produces an abundance of vegetative dry matter that is maintained for a long period of time. These characteristics are the antithesis of most qualities breeders select for in short season environments (Campbell *et al.*, 1978a). In selecting for early maturity, the vegetative period of growth is minimized so the reproductive period can be extended. The amount of dry matter that can be produced by any crop species in a 110-day growing season and at low mean temperatures is finite. Dry matter partitioning into leaves and stems that constitute the reproductive framework will be minimized while dry matter partitioned into reproductive structures will be maximized (*i.e.*, optimization of harvest index). One feature that makes a crop plant competitive and that can be selected for in short season areas is rapid seed germination at low temperatures and vigorous early plant growth.

Brassica campestris cultivars are suited to many parts of Alberta because they can mature in 95 to 100 days. The cost of this early maturity is lower seed yield, and reduced oil and protein percentages in the seed, as compared to *B. napus* cultivars. An effort is being made to reduce the time required to produce a *B. napus* crop from 115 to 120 days observed in some locations to fewer than 110 days. Breeders are selecting for early first flower dates, high harvest indices as well as the fewest days from seeding to harvest. The length of the seed-filling period for rapeseed, unlike that of cereals (Daynard and Kannenberg, 1976; Evans, 1975) is not correlated with yield (Campbell *et* *al.*, 1978a). As yet, the effect of these breeding strategies on the competitiveness of *Brassica* has not been assessed.

2.1.2 *Brassica* Species

2.1.2.1 The Origin and Use of Agriculturally Important *Brassica* Species

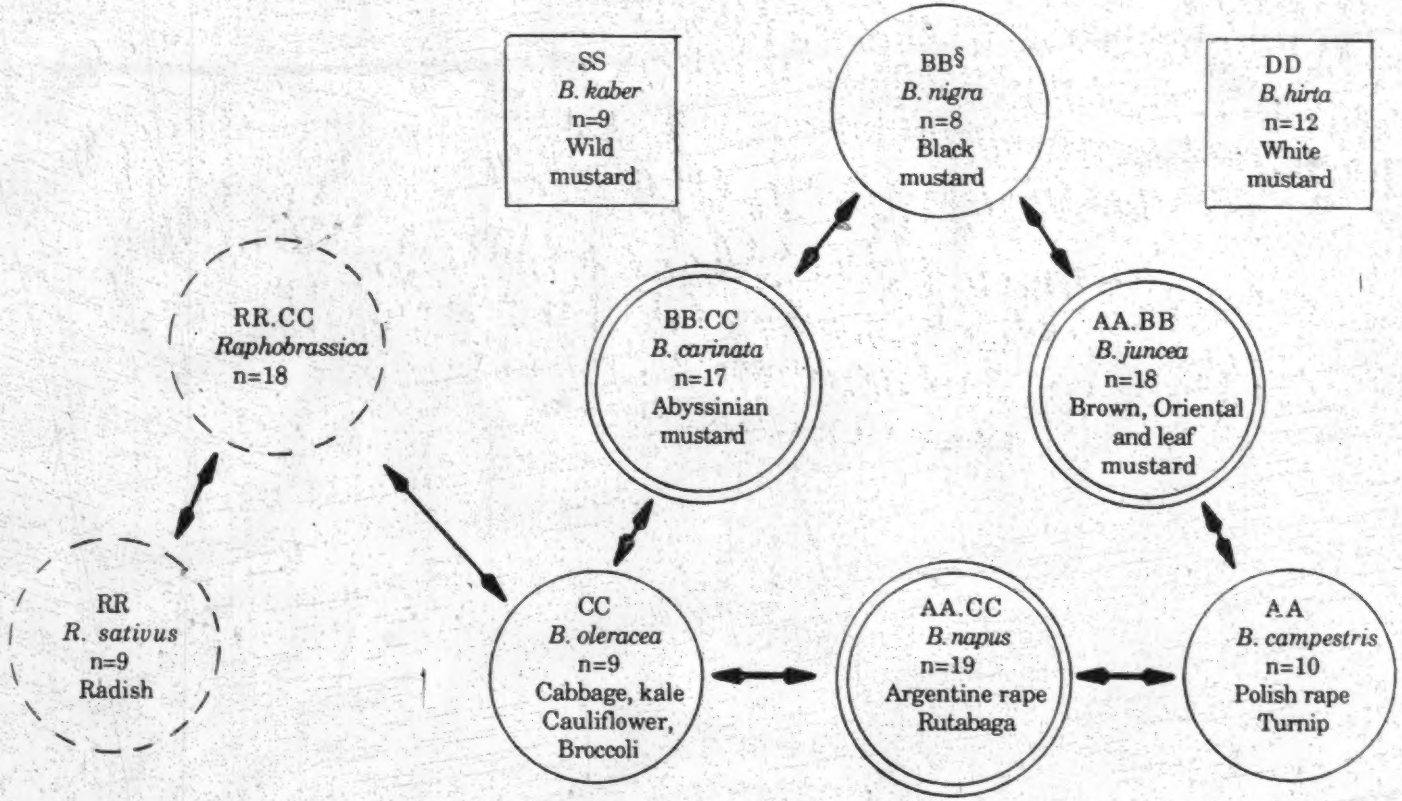
Of the 3.8 million ha of rapeseed grown for vegetable oil and animal feed purposes in Canada in 1987, 1.2 million ha was grown in Alberta (Thomas, 1989, pers. comm.; Rakow *et al.*, 1987). *Brassica campestris* , known as Polish or turnip rape is the most extensively grown species in Alberta (Rakow *et al.*, 1987). Spring Argentinian type rape, *B. napus* , can be grown in longer season areas of the prairies. Both spring and winter annual forms of *B. napus* can be grown in eastern Canada.

Brassica campestris and *B. napus* cultivars grown for human and animal consumption must meet certain quality standards set out by the Canola Council of Canada to be known as canola. For rapeseed to be designated as a canola-type, the oil component of the seed must contain less than 2% erucic acid, and the solid component of the seed must contain less than 30 micromoles of any mixture of 3-butenyl glucosinolate, 4-pentyl glucosinolate, 2-hydroxy-3-butenyl glucosinolate and 2-hydroxy-4-pentenyl glucosinolate per gram of air-dry, oil-free solid (Kondra, 1985).

Mustard is grown commercially under contract for the condiment trade. Only 184,500 ha were seeded to mustard in Canada in 1986. All the mustard was grown in the three prairie provinces (Canadian Grains Industry Statistical Handbook, 1987). The most commonly grown type is yellow mustard (*B. hirta* Moench=*Sinapis alba* L.). Brown-seeded and yellow-seeded Oriental types of *B. juncea* (L.) Coss. are also grown.

The botanical relationships of agriculturally important *Brassica* crops was not well understood until the 1930's when the Japanese scientist U theorized about the relationship which is now known as the triangle of U (Figure 1). The three amphidiploid species, *B. carinata* A. Br., *B. napus* , and *B. juncea* are natural hybrids of the diploid species *B. nigra* (L.) Koch, *B. campestris* and *B. oleracea* L.Wild mustard (*B. kaber* (DC.) Wheeler=*S. arvensis* L.) and yellow mustard (*B. hirta*=*S. alba*) are more distantly related (Downey *et al.*, 1975).

Figure 1. Nuclear genome and chromosome relationships of some economically important *Brassica* species and related genera[†].


SS
B. kaber
n=9
Wild
mustard
BB[§]
B. nigra
n=8
Black
mustard
DD
B. hirta
n=12
White
mustard
RR.CC
Raphobrassica
n=18
BB.CC
B. carinata
n=17
Abyssinian
mustard
AA.BB
B. juncea
n=18
Brown, Oriental
and leaf
mustard
RR
R. sativus
n=9
Radish
CC
B. oleracea
n=9
Cabbage, kale
Cauliflower,
Broccoli
AA.CC
B. napus
n=19
Argentine rape
Rutabaga
AA
B. campestris
n=10
Polish rape
Turnip

[†] Synthesized from Downey *et al.*, 1975 and Williams and Hill, 1986.

[§] The eight species included in the triangle of U are enclosed by solid circles.

2.1.2.2 The 'Morphophysiology' of Rapeseed/Canola

Canola growth and development can be divided into four main stages. These are 1/ vegetative; 2/ formation of the plant framework and flowering; 3/ pod development; and 4/ seed development (Bilsborrow and Norton, 1984). Weeds could affect plant growth at any of these stages, but there may be 'critical points' in canola development where competition from weeds would have a larger effect on seed yield than at other times.

Canola seedlings generally emerge four to 10 days after seeding (AGDEX 149/20-1, 1985). The epigeal germination habit of canola means that the growing point is above the soil surface between the two cotyledonary leaves. Weed competition at this early stage would not affect final seed yield unless the plants were competing for resources. It is more likely that plant disease, insect damage or hail damage to the growing point would cause the plant to die. The stand would be thinned but yield would not necessarily be reduced (McGregor, 1987).

The number of leaves produced between germination and floral initiation is dependent on variety, season and seeding date (Daniels *et al.*, 1986). Early maturing spring-seeded canolas, adapted to western Canada, will generally produce less than 12 true leaves (Downey *et al.*, 1975). The first three or four leaves should be large to produce a photosynthetically active leaf area quickly. These initial leaves are important for the production of new leaves and roots (Downey *et al.*, 1975). Stress imposed by weed competition during the leaf production stage is not likely to alter the number of leaves initiated but could change the size of the individual leaves. As leaves are the main source of photosynthate before flowering (Inanga *et al.* 1979), a reduction in leaf size and concomitant reduction in photosynthetic capacity will affect subsequent growth. Dry matter production by winter canola plants defoliated prior to flower initiation was reduced by 33% at anthesis and final seed yield was 21% less than for the undefoliated control (Evans, 1984).

The beginning of the framework development phase of growth coincides with bolting (extension of the internodes). The apex of the plant has been in the reproductive phase of development for some time before this event as flower buds on the terminal raceme are well developed at bolting (Scarisbrick and Daniels, 1984). Floral initiation also occurs in the axillary buds of the upper main leaves which produce the primary branches. Axillary buds on primary branches in turn give rise to secondary branches, and they in turn can develop tertiary branches etc. (Daniels *et al.*, 1986)

Leaves are the major source of photosynthate at the onset of flowering. They provide the photosynthate required for initial floral development and early stem growth (Rood *et al.*, 1984). As canola stems are photosynthetic organs, they eventually provide most of the assimilate used in their growth (Rood *et al.*, 1984). During the bolting-flowering period stem area and weight are maximized (Bilsborrow and Norton, 1984). Major *et al.* (1984) found that a portion of the labelled $^{14}CO_2$ applied to stems was incorporated into relatively inert, structural carbohydrates. Lower leaves exported assimilates primarily to the root and lower stem. The lower stem exported to the roots while the upper portion of the stem exported assimilates to developing pods and seeds (Major *et al.*, 1978). Evans (1984) found that leaf removal during the stem elongation period reduced dry matter present at anthesis by 36% and final seed yield by only 20%. These plants were able to compensate for the early dry matter loss in their post-anthesis growth. The most sensitive growth stage to defoliation and shading treatments was the commencement of the stem elongation phase. The limitation of assimilate at this time reduced dry matter accumulation from flowering to maturity so that the plants were shorter and had fewer flowers, pods, seeds per pod, and lower seed weights (Evans, 1984).

A high plant densities, whether it is the canola crop alone, or canola plus weeds, limits the resources available to each plant (Harper, 1961). Stress imposed by the presence of weeds could affect the transition of the apex from a vegetative to a reproductive stage and influence overall plant structure by limiting the size of assimilatory organs. A reduction in leaf area in the rosette affects the size of stem to follow. Axillary buds act as sinks that require photosynthate to develop branches and canola plants grown at high population densities, where resources are limited, generally have few branches (Degenhardt and Kondra, 1981a).

The number and size of leaves produced and the stem structure determine the crop canopy architecture (Daniels *et al.*, 1986). The canopy changes during this framework development stage. The true leaves that were present in the rosette and are at the bottom of the canopy senesce. The rate of senescence varies with cultivar and can be accelerated by environmental stress (which could include the presence of weeds) (Major *et al.*, 1984). Some of the original leaf area is replaced by bracts occurring at nodes that are placed higher in the canopy. The bracts are smaller than the true leaves and contribute to the 'ideal' pyramidial plant form that allows light to penetrate into the plant canopy (Downey *et al.*, 1975). Despite the canopy architecture, Bilsborrow and Norton (1984) found that plant parts below a height of 80 cm in winter canola were in the shade. A further limitation to the efficient utilization of incoming radiation was that 30 to 60% of the incident radiation may be reflected or absorbed by the flowers at the top of the canopy (Yates and Steven, 1987).

Because canola flowering continues over a 14 to 21-day period (Downey *et al.*, 1980), the pod development and plant framework stages overlap. At the pod development stage, pod area and hull weight are maximized (Bilsborrow and Norton, 1984). Most pods are derived from flowers that have opened in the first 14 days of the flowering period. Consequently, more pods are carried on the terminal raceme than on the branches (Tayo and Morgan, 1975). The duration of flowering becomes progressively less on later developing inflorescences so that flowering finishes at approximately the same time (McGregor, 1981). The onset and duration of flowering are variable. Cool weather delays the onset and the numbers of flowers which open each day. Low plant density encourages secondary branching which can extend flowering (Downey *et al.*, 1980). Conversely, at high plant densities (which could be caused by the presence of weeds) branching is reduced. This would shorten the flowering interval.

Once the flower is fertilized the sepals, petals and stamens are dropped within two to three days and the young pod becomes visible a day later (Tayo and Morgan, 1975). Up to 16 days after flowering most assimilate is used to develop the pod hull (Diepenbrock and Geisler, 1979). Bilsborrow and Norton (1984) reported that pods must achieve a minimum size before seed development proceeds. Canola plants produce many more buds and flowers than pods. Only 40 to 55% of the flowers that open develop into pods that are retained until harvest (McGregor, 1981).

Inter- and intra-plant competition is important in determining pod and seed survival (Clarke, 1979). Flowers that are fertilized early have the time advantage of garnering more nutrients and assimilates (Daniels *et al.*, 1986). Canola leaf area is greatest at the beginning of flowering (Clarke and Simpson, 1978a) and therefore more leaf assimilate should be available to developing pods at this time. Major *et al.* (1978) showed that a higher percentage of ^{14}C-labelled assimilates was in the seeds of lower (older) pods than in upper (younger) branch pods. This pattern may be altered by high plant populations where lower pods can be shaded by later developing ones (or possibly by weeds) so that the upper portion of the terminal raceme may actually contribute a greater proportion of the final seed yield (Daniels *et al.*, 1986). Bilsborrow and Norton (1984) reported that as little as 20% of the incoming radiation was available to the lowest pods in the canopy. This partially explains the development of fewer pods with fewer and smaller seeds by lower-most canola branches (Clarke, 1979). The sensitivity of early pod development to shortages of carbon assimilates is a second 'critical' period of canola growth identified by Evans (1984).

Photosynthate derived from the leaves is used for the initial pod growth. As the pod canopy develops, leaf area declines and stems become a more important site of assimilation (Rood *et al.*, 1984; Chapman *et al.*, 1984). Pods are capable of assimilating $^{14}CO_2$ and eventually take over as the main producer of assimilate used for seed growth. Even after pods can produce enough assimilate to support their own development, however, they still act as sinks for photosynthate exported by other organs (Major *et al.*, 1978).

Seed yield is closely associated with the number of pods retained by the canola plant (Tayo and Morgan, 1975). Pod (and seed) mortality can occur until maturity due to intra-pod competition for light and nutrients (Bilsborrow and Norton, 1984). Weeds or disease which restrict the efficiency of light interception, assimilate fixation and its distribution within the plant, could affect final seed yield by limiting the number of pods maintained.

The final developmental stage emphasizes the dry matter accumulation associated with seed development and filling (Bilsborrow and Norton, 1984). However, the pod development and seed development stages overlap. The number of potential ovules per pod is determined before the flower opens. The actual number of seeds per pod is determined at fertilization (Daniels *et al.*, 1986). Seed number per pod and seed size vary within cultivars and can be altered by plant density and moisture availability (Clarke and Simpson, 1979). The number of seeds per pod declined between the end of flowering and maturity in both spring and winter-sown canola. The change in numbers was less on the main raceme than on the branches that were deeper in the canopy (Clarke, 1979; Mendham and Scott, 1975). This suggests that there is not only inter-pod competition for assimilate but inter-seed competition as well.

Diepenbrock and Geisler (1979) identified three stages of pod and seed development. Initially, pod hull growth was greater than seed growth on a weight basis. During a second phase of development, hull dry matter decreased as nitrogen from the hull was exported to rapidly developing seed embryos. The rate of dry matter accumulation in the seed was high at this stage and the protein content of the seed declined as the oil content increased. In the third phase, the pod hulls lost dry matter and the rate of seed growth slowed dramatically. The length of time spent in each stage was affected by the location of the pod on the plant. Seed filling of spring-type canola is usually complete 35 to 45 days after the flowers first open. The seeds are physiologically mature at approximately 40% moisture. As the seeds begin to change colour they lose 2 to 3% moisture per day (AGDEX 149/20-1, 1985).

Seed survival and development is dependent on photosynthate provided by the leaves, stem and pods. Rood *et al.* (1984) estimated that at the onset of seed ripening, the pods were the principal sites of $^{14}CO_2$ assimilation. They accounted for 46% of the labeled carbon. Seventeen and 29% of the label was found in the stem and leaf material, respectively. Although the seeds contain chloroplasts, the photosynthetic activity of the seeds estimated by Brar and Thies (1977) was only 1% of the total for the whole plant.

Seed yield is dependent on a series of events. There are periods during development that are more sensitive to environmental stress such as high plant densities or low soil moisture. These stresses will result in altered plant form and function (Adams, 1967). Final seed yield is a product of the balance between resource production and allocation. In canola, potential yield may be determined by the growth up to the time of flowering. Mendham and Scott (1975) reported that there was a critical plant size that winter canola had to attain by the time of floral initiation. Final seed yield was proportional to weight for plants below the critical value. Assimilate production in canola plants is not static. Leaves, stems and pods act as the principal sources of photosynthate at different stages in the development of canola. Assimilation is proportional to the weight of each organ at the time carbon dioxide is taken up (Rood *et al.*, 1984). The actual yield components are determined relatively late in the developmental sequence. Pod number and the initial number of seeds per pod are dependent on the availability of photosynthate at flowering. Inter-pod and inter-seed competition for resources determines the number of pods and seeds per pod maintained until harvest (Bilsborrow and Norton, 1984). Weeds have the potential to alter carbon allocation at many stages during canola development. Their influence on overall dry matter production before flowering, pod production and seed filling is critical to the effect that weed growth will have on final seed yield of canola.

2.1.2.3 Triazine-Resistant *Brassicas*

Farmers have increased their use of herbicides since the 1940's and they have reduced the use of crop rotation (Haas and Streibig, 1982). The evolution of herbicide-tolerant plant biotypes was predicted in the 1950's (Harper, 1956; Abel 1954). Harper (1956) theorized that by hybridization a new species could suddenly arise or a new herbicide-tolerant weed strain might evolve under the influence of selection.

Several conditions have contributed to the development of herbicide-tolerant plants. These are continuous or repeated application of one herbicide, often one with residual activity or one applied frequently in one season (*e.g.* paraquat (1,1'-dimethyl-4,4'-bipyridinium ion)), or a reduction in crop rotation and mechanical weed control measures (Gressel and Siegel, 1982).

Harper (1956) does not differentiate between herbicide resistance and tolerance. For purposes of this review, herbicide resistance means that plants can withstand high concentrations of herbicides (above the recommended rates) that would normally kill the wild plant type. Resistance is usually the result of binding site modification (Arntzen *et al.*, 1982). Tolerant plants will survive herbicide rates that would normally kill the species. These rates will not be as high as those resistant plants can withstand. Tolerance can be based on ecological and phenological adaptations (Shaaltiel and Gressel, 1986; Anderson 1970) as well as on differential metabolism, uptake or translocation (Werner and Putnam, 1980).

An alternate approach to developing a selective herbicide to control cruciferous weeds in *Brassica* crops is breeding crops that are resistant to existing chemicals that control these weeds effectively.

It was the discovery of two triazine-resistant bird rape (*B. rapa* L.=*B. campestris*) populations in Quebec (Maltais and Bouchard, 1978) that allowed triazine resistance to be transferred into *Brassica* crops. Once it was known that the resistance was inherited maternally (Souza Machado *et al.*, 1978), triazine resistance was added to the *B. napus* variety Regent and the *B. campestris* varieties Candle and Torch (Beversdorf *et al.*, 1980). This entailed crossing the triazine-resistant *B. campestris* pod parent with each cultivar, was followed by five or six backcrosses with the pollen parent to add back desirable characteristics such as low erucic acid and low glucosinolates (Weiss, 1982).

The first triazine-resistant line developed with *B. napus* cv Tower as the recurrent pollen parent was licensed in Canada as cv OAC Triton in 1984 (AGDEX 149/33-11, September 1985). Since then, four other varieties have been licensed, cv Tribute in 1985 (AGDEX 149/33-13), OAC Triumph in 1987 (Registration No. 2825), Stallion in 1989 (Registration No. 3106) and AC Tristar in 1990 (Registration No. 3314). The newer cultivars show improvement over OAC Triton in that Tribute is earlier and has slightly higher oil content than OAC Triton. AC Tristar is higher yielding and has two percent more oil but less protein than Tribute. OAC Triumph has better seed yield, and lodging resistance and a lower percentage of green seeds than OAC Triton, but is approximately 2 days later in maturity. Stallion is higher yielding than OAC Triton, Tribute and OAC Triumph but matures four days later than Tribute.

Gressel and Ben-Sinai (1985) compared the competitive ability of *B. napus* cv Regent and the eighth backcross of triazine-resistant Regent by seeding them alone or as a mixture of the two lines. When grown in a mixture, the triazine-resistant Regent dry weight, number and weight of pods and seed yield were less than one-third of corresponding values for triazine-susceptible Regent.

Donnally and Hume (1984) reported that triazine-tolerant *B. napus* plants showed lower photosynthetic rates and dry matter production than the non-tolerant parents when grown at 25/20 C day/night temperatures. No difference could be found in plants grown under a 15/10 regime. The authors suggested that the lower yields of triazine-tolerant *B. napus* resulted from reproductive problems rather than from reduced photosynthesis.

The decision to use a triazine-resistant variety has to be carefully considered by the producer. Is it worth seeding the lower yielding triazine-tolerant canolas in fields were there are triazine herbicide residues or are there other cropping options? Is it worth while to use triazine herbicides to manage weeds such as stinkweed (*Thlaspi arvense* L.) and wild mustard or are there other weed control options where conventional canola cultivars could be used? Forcella (1987b) reported that with wild oat (*Avena fatua* L.) densities of 25 to 30 plants/m^2 it was advantageous to use triazine-resistant *B. napus* cv Tower (=cv OAC Triton) rather than the higher yielding triazine-susceptible Tower. Although the total biomass and seed yield of the resistant Tower were less than those of the triazine-susceptible Tower at all weed densities, the biomass and seed yield lost when 25 to 30 wild oat plants/m^2 could not be controlled in triazine-susceptible Tower was larger than the biomass and seed yield reduction associated with triazine-resistance.

2.1.2.4 *Brassica* Hybrids

Allard (1960 p. 468) defined a hybrid as "the product of a cross between genetically unlike parents" and heterosis as "hybrid vigour such that an F_1 hybrid falls outside the range of the parents with respect to some character or characters, usually applied to size, rate of growth, or general thriftiness". Percent heterosis is commonly expressed in a comparison with a mid-parent value[1] or the best parent value[2] (Sinha and Khanna, 1975).

Inter-specific hybridization has occurred naturally in *Brassica* species. Hutcheson *et al.* (1981) reported a subspecies between *B. campestris* spp *sarson* Prain 'R-500' and *B. napus* L. var *oleifera*. Many hybridizations have been made between species included in the triangle of U, in support of the theory that *B. carinata*, *B. juncea* and *B. napus* were natural hybrids arising from various combinations of *B. nigra*, *B. oleracea* and *B. campestris*. These test hybridizations have been made by conventional *in vivo* hand pollinations (Labana *et al.*, 1983) and by protoplast fusion techniques (Glimelius, 1988).

Heterosis values for seed yield ranging from21 to 50% better than parental seed yields have been reported for winter rapeseed F_1 hybrids (Schuster and Micheal, 1976; Morice, 1978; Shiga, 1976; Buson, 1980). Heterosis for total number of branches, number of primary branches, one-litre seed weight and 1000-seed weight was observed in a number of hybrids Shiga (1976) evaluated. Guan *et al.* (1980) found heterosis for the number of primary branches and pods per plant in the *B. napus* hybrids he tested. These hybrids also had more stomata per unit area of pod surface, longer flowering time, higher leaf area index, chlorophyll content and photosynthetic rate which suggests that hybrids have a greater photosynthetic capacity which could account for their more vigorous growth and higher seed yields.

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[1] Percent heterosis= $\dfrac{F_1}{\dfrac{P_1+P_2}{2}} \times 100$

[2] Percent heterosis = $\dfrac{F_1 - \text{better parent}}{\text{better parent}} \times 100$

In Ontario, Grant and Beversdorf (1985a) observed rapeseed seed yield heterosis of 72% (based on the highest yielding parent). When both European and Canadian lines were tested in a 6 x 6 diallel most of the hybrids did not differ from their parents in 1000-seed weight, percent protein, percent oil, plant height or lodging resistance.

Crosses between *B. napus* plants of different geographic origin appear to be more productive than crosses between lines of the same origin (Sernyk and Stefansson, 1983; Grant and Beversdorf, 1985a; Lefort-Buson *et al.*, 1987a). Lefort-Buson *et al.* (1987b) stated that there is a relationship between heterosis and genetic distance, but that genetic distance and combining abilities of selfed lines have to be considered when assessing F_1 performance.

The level of heterosis for seed yield of some F_1 hybrids produced by hand crossing appears to justify the added costs involved in hybrid seed production. Often high heterosis on a single plant or small plot basis does not translate into high heterotic yields in field-scale operations due to the low heritability of factors contibuting to yield (Sinha and Khanna, 1975). This is perhaps the case with hybrids that have been tested in western Canada recently.

There is very little information that would indicate whether the reported early vigour of F_1 *Brassicas* translates into a greater tolerance of weed competition. Hühn (1981) compared nine plant characteristics (yield per plant, pods per plant, 1000-seed weight *etc.*) of two inbred winter swede rape lines and their hybrid growing in mixtures. The hybrid appeared to have a high competitive ability when grown with the two rapeseed inbreds.

2.1.2.5 Triazine-Resistant *Brassica* Hybrids

One method to overcome the lower yields of triazine-resistant canola cultivars is the use of triazine-resistant hybrids. Grant and Beversdorf (1985b) crossed atrazine-resistant *B. napus* cv Regent with eight high yielding *B. napus* lines from Canada, Sweden and Denmark. The F_1 hybrids were intermediate to the parents for seed yield, maturity, plant height and oil content. The results showed that triazine-resistant hybrid cultivars can perform better than existing triazine-resistant hybrids but high levels of heterosis for seed yield did not materialize.

2.1.2.6 Yield Potential of Selected *Brassica* Cultivars in Canada

The yield potential of *B. napus* varieties under optimum growth conditions is greater than *B. campestris* (Thomas, 1984). Results of the Western Canola Co-operative Tests (1982-1986) showed that *B. napus* cv Regent and *B. campestris* cv Tobin yielded 85 and 90%, respectively of *B. napus* cv Westar. The triazine-resistant *B. napus* cultivars OAC Triton and Tribute yielded 68 and 70% of Westar (Canola Growers Manual Update, 1987)

In the Eastern Canola Co-operative Tests, the yield performance of *B. napus* cv Topas equalled the Westar check yield while cv Hanna yielded 4% better than Westar. The yield of OAC Triton was 13% less than Westar while Tobin yielded only 89% of the check. The winter canola variety Tandem yielded 133% of the Westar check. This exhibits the higher yield potential of winter rapeseed in adapted areas versus spring *B. napus* cultivars (Canola Growers Manual Update, 1987).

Since 1986, at least ten *B. napus* hybrids have been evaluated in the Western Canola Co-operative Tests. In some cases, hybrid yields have not been better than those of the standard check varieties. This is due in part to the 'long season nature' of this material. Some lines require 120 to 130 days to mature. Certain hybrids have performed well in specific areas of the prairies but projections of seed yield heterosis of 40 to 50% (Sernyk and Stefansson, 1983; Grant and Beversdorf 1985b) based on hand-crossed hybrids made in the early 1980's have not been realized (Thomas, 1989, pers. comm). The *B. napus* hybrid, Hyola 40, was registered in 1989. It is 2 days later in maturity than Westar and yields 6% better than Westar in areas where it is adapted (Thomas, 1989, pers. comm.)

Breeders have recognized a number of features of *B. juncea* that are desirable such as yellow seed coats, drought tolerance, early maturity, better disease resistance (especially blackleg), high seed yield and shattering resistance (Pawlowski, 1971). Many of these features would be valuable if incorporated into canola-quality rapeseed cultivars.

The Oriental mustard varieties Domo and Cutlass mature in approximately 93 days. Cutlass, which is a newer cultivar, yields more than Domo but has a lower oil content (AGDEX 142/33-11, August 1985). In 44 tests conducted in Saskatchewan between 1982 and 1984, Domo mustard out-yielded Westar canola by 17% (Woods, 1984).

2.2 Crop Density

2.2.1 Plant Demography and the Yield-Density Relationship

"Demography deals with the quantitative aspects of birth, growth, reproduction and death in a population" (Solbrig, 1980). In natural ecosystems, population dynamics and the action of natural selection have been studied by collecting demographic data. Some aspects of plant demography have been emphasized in agricultural ecosystems because of the special conditions that are created such as uniform genetic plant populations and the emphasis on harvestable yield per unit area (Snaydon, 1980). Agronomists and foresters have collected demographic data to meet practical objectives such as optimal sowing densities for timber or life histories of noxious weeds (Solbrig, 1980).

Choosing the correct unit of plant population to study is not an easy task. Whole plants or parts of plants may be used. If parts of plants are used, Holliday (1960a) suggested the unit should be easily identifiable such as tillers in grasses.

Plant populations should be defined in terms of plant density per unit area and plant spatial arrangement. Willey and Heath (1969) stated that "few workers have distinguished between these two factors and many plant population experiments have in effect studied the combined effects of both". This is particularly true in agricultural systems where different plant densities are studied at constant row widths.

The relationship between plant density and yield/weight per unit area is linear when plant populations are low. Eventually, the yield/weight per unit area becomes independent of seeding rate and there is no gain in yield/weight at higher plant populations. This density-dry matter production relationship is known as the 'Law of Constant Final Yield' (Harper, 1977 p. 154).

The density-dry matter relationship may be altered by stress which Grime (1977) defined as "the external constraints which limit the rate of dry-matter production of all or part of the vegetation". Plants respond to the stress imposed by density in two ways. They may exhibit plastic responses by varying the amount of growth of organs. There may also be differences in mortality of individuals as a whole or as parts, such as branches or flowers.

Crop yield may also require some definition. Mean yield per plant obtained by dividing the number of plants into a value taken on an area basis is not the same as yield per individual plant. Yield per individual plant does not necessarily reflect yield on an area basis either (Willey and Heath, 1969).

2.2.2 Yield-Density Equations

Holliday (1960a) suggested that the relationship between crop yield and plant population could be expressed by two types of curves. A parabolic curve most often describes yield that is derived from the reproductive phase of growth. An asymptotic curve characterizes yields that are a product of vegetative growth.

The relationship between seed yield and population density of a number of crops, *e.g.* corn (Bunting, 1971) and barley (Willey and Heath, 1969) had a parabolic shape while data for fodder rape (*Brassica napus* var. *biennis*) (Holliday, 1960b), subterranean clover (*Trifolium subterraneum* L.) and Wimmera ryegrass (*Lolium rigidum* Gaud.) (Donald, 1954) exhibited asymptotic response curves. The response of small grain cereal straw (Holliday, 1960a) and corn stover (Bunting, 1971) also assumed an asymptotic relationship between yield per unit area and plant density.

Yield density relationships have been studied in many agricultural crops. It is only within the last 30 years that mathematical models have been used to aid in the interpretation of data and for predictive purposes (Willey and Heath, 1969). Of the numerous yield-density models that have been proposed (Holliday, 1960a, Willey and Heath, 1969), increasingly only three are being used (Mead, 1979): the reciprocal equation for 'asymptotic' responses developed by Shinozaki and Kira (1956), Holliday's (1960a) parabolic model and Bleasdale's (1966) power version of the Shinozaki and Kira equation.

Shinozaki and Kira (1956) observed there was a linear relationship between the reciprocal of mean plant weight and plant density. They expressed this relationship as:

$$(1) \quad \frac{1}{w} = a + bp$$

where w = mean weight per plant, p = plant density and a and b are constants. This relationship has been confirmed for a number of crop species (Harper, 1977 p. 156). The equation is open to criticism as very small plants at high densities contribute more to the regression equation than they should. Harper (1977 p.156) suggested that proper weighting of data (*i.e.*, by using log values) may be important.

Holliday (1960a) proposed that a quadratic model would fit the parabolic yield situation, where the relationship between the reciprocal of the yield per plant and density was no longer linear. In this equation,

$$(2) \qquad \frac{1}{w} = a + bp + cp^2$$

w = mean weight per plant, p = plant density and a, b and c are constants.

Like the Shinozaki and Kira (1956) equation, the Bleasdale (1966) equation is a reciprocal equation derived from a simple logistic growth curve (Willey and Heath, 1969):

$$(3) \qquad \frac{1}{w^{\theta}} = a + bp$$

where w = mean weight per plant, p = plant density and θ, a, and b are constants. When $\theta = 1$, the yield is asymptotic. If $\theta < 1$ the yield curve has a parabolic shape (Willey and Heath, 1969).

Mead (1979) summarized the state of modelling yield-density relationships when he wrote that the Bleasdale model and Holliday's reciprocal equations "provide a good framework within which to investigate practical yield-density relationships and this is one aspect of competition experiments which is in a satisfactory state of development".

The degree of intra-specific competition in additive experiments can be estimated using equation 1. The ratio of b/a is used as a measure of intra-specific competitive stress (Spitters 1983a; Spitters 1983b). Inter-specific competition between two or more species can be handled by the following multiple linear regression equation:

$$(4) \qquad \frac{1}{w_1} = a + b_{1,1}p_1 + b_{1,2}p_2$$

where w = mean weight or seed yield per plant of species 1, p = plant density of species 1 or species 2 and b are constants. The coefficient b_2 quantifies the effect of inter-specific competition. Species 1 has an equal effect on $1/w_1$, as adding $b_{1,1}/b_{1,2}$ plants of species 2.

2.2.3 Effect of Crop Spatial Arrangement on *Brassica* Yield

2.2.3.1 Seeding Rate and Row Spacing

Unlike yield-density responses for small-grained cereals (Guitard *et al.*, 1961; Larter *et al.*, 1971), the yield-density responses of *B. napus* and *B. campestris* varieties grown in western Canada have been variable.

In experiments examining the effect of seed size and seeding rate on rapeseed yield, Kondra (1977) observed that seeding rate had a significant but variable effect on *B. napus* cv Zephyr and *B. campestris* cv Span yield grown in the Edmonton area. The 6 kg/ha seeding rate produced the highest yield, as had been previously shown (Kondra, 1975). The effect of seeding rate on oil and protein content also varied. Protein content was higher at high planting densities while oil content was reduced. No differences in *B. campestris* (Candle and Tobin) or *B. napus* (Altex and Westar) yield were measured when the varieties were seeded at 7 or 14 kg/ha at Beaverlodge (Christensen and Drabble, 1984).

Yield of Westar canola (*B.napus*) increased as seeding rates increased from 3 to 6 and 9 kg/ha at Scott, Saskatchewan (Ukrainetz, 1985). The author noted that moisture conditions were good in that location in 1985. Previous work conducted under drier conditions had shown that canola yield was maximized at seeding rates between 4 and 8 kg/ha at 23-cm row spacings. Brandt (1985) examined the influence of seeding date and seeding rate on the yield of several oilseed crops at Scott as well. Delayed seeding reduced yield in Tobin (*B. campestris*), Westar *(B. napus*) and OAC Triton (*B. napus)* canola but did not affect Gisilba (*S. alba*) yellow mustard yield. The four cultivars were seeded at 2, 4, 6 or 12 kg/ha, and the yield response differed between the cultivars tested. Tobin yield was optimized between the 4 and 6 kg/ha rate while triazine-tolerant OAC Triton yield increased as seeding rate increased to the 12 kg/ha rate. Seeding rate did not affect yields of Westar canola or Gisilba yellow mustard.

Most researchers studying the effect of seeding rate on canola yield have not presented the plant densities achieved for the seeding rate used. Clarke *et al.* (1978b) did include this information in their paper outlining the effects of seeding method and rate on the yield of *B. napus* cv Tower. Seed yield increased as the seeding rate increased (2.5 kg/ha=56 plants/m^2; 5 kg/ha=106 plants/m^2; 10 kg/ha=156 plants/m^2; 20 kg/ha=295 plants/m^2). Plant stands at each seeding rate were similar for broadcast seeded and drilled plots. The drill-seeded canola yields were higher than broadcast seeded canola at the same rate. This was particularly true at the lower seeding rates. The authors attributed the yield superiority of the drill-seeded canola to the effects of competition on plant morphology and on assimilate supply and distribution.

Fulkerson (1971), working in Ontario, also found that the dry matter yield of fodder rape grown in rows was higher than after broadcast seeding. Maximum dry matter production was obtained when fodder rape was seeded in rows at the lowest seeding rate tested (0.56 kg/ha).

Plant stand information was critical in McGregor's (1987) work on the ability of canola to recover from hail injury. *Brassica campestris* cv Torch and *B. napus* cv Tower stands were thinned to a range of densities between 4 and 86 plants/m^2, a number of times throughout the growing season, beginning at the one to two-leaf stage. Seed yield was not directly proportional to plant density. Plant stands thinned to 40 plants/m^2 yielded approximately 80 percent of the control population of 100 to 200 plants/m^2. This showed that the plants left after thinning could easily compensate for the plants that were removed.

The yield-stand relationship below 22 plants/m^2 was linear in an experiment conducted by McGregor (1987). A similar response was observed at Melfort, Saskatchewan when canola was seeded at low densities. *Brassica napus* cv Tower and Midas showed yield increases proportional to stand density in plant populations of 2 to 18 plants/m^2. The yield at the highest density was approximately 800 kg/ha (14 bu/acre) for both cultivars (Anonymous, 1980).

The effect row spacing has on rapeseed yield has been more definitive than the effect of seeding rate on rapeseed production. Most commercial seed drills have furrow openers that are 15, 18 or 23 cm apart. Christensen and Drabble (1984) reported that decreasing row spacing from 23 cm to 15 cm and from 15 cm to 7.5 cm increased *B. campestris* cv Candle yield by 20 and 26 percent and *B. napus* cv Altex by 26 and 38 percent, respectively, for rapeseed grown at Beaverlodge. At Scott, Saskatchewan, the highest *B. napus* cv Westar seed yields were obtained at a row spacing of 11 cm versus 23 cm and 30 cm row widths. Morrison *et al.* (1990) reported that Westar grown in Manitoba yielded more in 15-cm rows than in 30-cm rows.

Early work by Kondra (1975) showed that yields of *B. campestris* cv Span and *B. napus* cv Zephyr yields did not vary consistently with row spacing. The trends in yield supported the premise that rapeseed planted at narrow row spacings generally produces higher yields.

More recently, Mahasi (1986) showed that *B. campestris* cv Candle and Tobin yielded best in 11.5-cm rows while yields of *B. napus* cv Westar and 81-58412K did not differ when grown in 11.5 or 23-cm rows.

2.2.4 Components of Seed Yield

The idea that yield could be defined by looking at components of the plant began in the 1920's. Early plant breeders looked to component analysis to define the attributes of high-yielding cultivars (Fraser and Eaton, 1983). More recently, scientists have looked at physiological traits as a basis for breeding higher yielding crops (Rasmusson and Gengenbach, 1984).

There is both a genetic and environmental component to physiological trait variation. Breeders need to know the genetic variability and heritability of yield components to make advances in breeding programmes. The heritabilities of *B. napus* yield and yield components are generally low (Campbell and Kondra, 1978b). This largely accounts for the compensation between yield components that is observed when rapeseed is stressed. Despite the fact that the variation in yield and yield components is explained primarily by environmental factors, yield component analysis can be used to understand yield.

2.2.4.1 Plasticity of Plant Growth

Plants differ from animals in that an individual can be viewed as a population of parts. The size and form of individual units are often stable *i.e.*, flower size or weight or seed weight, but changes in the number of units mean that the size of the whole plant will vary with age and the environment (Harper, 1977 p. 195). The variability in the number of plant parts under different environmental conditions is known as plasticity. Bradshaw (1965) emphasized that plasticity can be expressed both morphologically and physiologically. Physiological changes are not easily observable and may be reversible. Since morphological changes stem from physiological ones, plasticity is most often based on morphological changes that occur during development and that result in permanent alterations in plant organs.

The proximity of neighbours affects the development of individual plants and plastic development is a method of assuring reproductive output of the plant when population density is high. Harper (1977 p. 196) points out that "a density-stressed individual [plant] is not simply a miniature version of its vigorous low-density counterpart". While individual plant dry weight tends to decline as the plant population density increases, the parts of the individual plant are not all changed proportionally. In agricultural crops, the optimum plant density for seed production may not be the optimum density for total dry matter production for the crop or even the variety (Bunting, 1971; Bunting, 1973). Plasticity is an essential feature of crop plants in that it assures yield stability.

The weight of seed produced by a plant can be viewed as the product of a number of yield components. For instance, cereal crop seed yield is a function of plants per unit area, fertile tillers per plant, spikelets per spike, seeds per spikelet and individual seed weight. The plastic response of yield components reflects the effect of the environment on the linear scheme of development of annual and biennial plants. In cereals, at least, there are periods that are 'critical periods' in the growth cycle (*e.g.*, time of double ridge formation, time of spikelet formation) during which stress will affect reproductive output (Adams, 1967).

The study of the effect of plant density on the plastic response of yield components has been more descriptive than analytical in nature (Harper, 1977 p. 198). Generally, yield components measured at maturity are plotted against plant density. Some characters remain stable even at high plant densities while other characters are very plastic. Stable characters are often under genetic control and can be changed by selection. Frequently the stability of one character (*e.g.*, seed size) is due to the plasticity of another (*e.g.*, number of flowers) (Bradshaw, 1965).

2.2.4.2 Effect of Crop Spatial Arrangement on the Components of *Brassica* Yield

2.2.4.2.1 Seeding Rate and Row Spacing

The way in which dry matter is proportioned into individual plant organs in agricultural crop plants is very important. The logarithmic relationship that occurs between total plant weight and plant density (described in section 2.2.2) can also be applied to individual plant components. Frequently, a component of yield will decrease more rapidly than total plant yield as plant density increases (Snaydon, 1980).

The components of oilseed *Brassica* yield are plants per unit area, pod-bearing branches per plant, pods per branch, seeds per pod, and individual seed weight (Thurling, 1974a).

Scarisbrick *et al*. (1982) examined the effect of three seeding rates on the yield and yield components of both winter and spring-sown *B. napus* cultivars. Populations of the cultivar Willi (spring-type) were established at 70, 120 and 185 plants/m^2. The mean plant dry weight declined as the population density increased. Plant height also declined as plant density increased. There was no difference in harvest index[3] , oil or crude protein content of the seed between plants at any of the densities. The highest seed yield was obtained at 120 plants/m^2 even though there were only 23 pods/plant compared to 37 pods/plant at 70 plant/m^2 and 20 pods/plant at 184 plants/m^2. The number of seeds per pod averaged 11 and did not differ between densities. However, the seed weight increased as the population density increased.

Degenhardt and Kondra (1981a) did not find any effect of seeding rate (3, 6 or 12 kg/ha) on seed yield, vegetative yield, or total dry weight of four *B. napus* species grown in the Edmonton area. Dry matter partitioning was affected by seeding rate as the harvest index was 27% less at the 12 kg/ha seeding rate than at 3 or 6 kg/ha. As seeding rate increased, seed yield per plant, branches per plant, and plant height decreased. Plant density had no effect on seed filling as the seed weights were the same for all seeding rates. This same lack of effect on seed filling of both *Brassica* species had been observed previously (Kondra, 1977).

Morrison *et al*. (1990) observed that the highest yields of Westar (*B. napus*) were achieved when the crop was seeded at 1.5 or 3.0 kg/ha. Increased branching compensated for the low plant density.

Seeding rate may affect the linear scheme of rapeseed development. While Degenhardt and Kondra (1981b) did not find that seeding *B. napus* at 3, 6 or 12 kg/ha affected seed yield or the number of days to first flower, increased plant density did decrease the days to last flower by 1 day between the 3 and 12 kg/ha rates. Increasing the seeding rate also decreased the days to maturity of the first pod and the seed formation period by 1 day for each 3 kg/ha increase in seed sown.

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[3] $\text{Harvest index (\%)} = \dfrac{\text{seed weight}}{\text{seed + stem weight}} \times 100$

Contrary to the previous report, both Clarke *et al.* (1978) and Clarke and Simpson (1978b) observed that rapeseed seed yield increased as plant seeding rate was increased from 2.5 to 20 kg/ha. The number of seeds per pod declined from 16 to 13 as the seeding rate increased while 1000-seed weight increased from 2.99 g at the 2.5 kg/ha seed rate to 3.27 g per 1000 seeds at the 20 kg/ha seeding rate.

McGregor (1987) found in his work on the effect of rapeseed plant density on recovery from hail injury that reducing the plant population of *B. napus* cv Tower and *B. campestris* cv Torch increased the amount of dry matter produced per plant. Dry matter accumulation peaked progressively later for plants grown at lower densities. This meant that maturity was delayed by up to 16 days when *B. napus* cv Tower was thinned to four plants/m^2. Plants at harvest had more than four times the branches and three times the number of pods as plants at the higher densities. Overall, more pods were produced by *B. campestris* cv Torch than *B. napus* cv Tower at all the densities tested. The number of seeds per pod increased as density declined in *B. napus* cv Tower while there was little effect of population density on the number of seeds per pod of *B. campestris* cv Torch. The effect of plant density on 1000-seed weight was variable. Seed weight generally increased as plant populations decreased in both *Brassica* species.

There are few reports that deal specifically with the effect of plant population on the components of *Brassica* yield. Most of the literature describes the effects of seeding rate on *B. napus* rather than on *B. campestris* and very few researchers have combined both *Brassica* species within one experiment. From a synthesis of the literature, one would expect the response of *B. napus* to increasing plant population stress to be a reduction in plant height, maturity, total dry weight, branches per plant, and pods per plant. Plant density, if it affects seeds per pod, tends to reduce it. The most varied response to seeding rates was observed in the weight of 1000 seeds. There were instances where high plant population had no effect, and also instances of increased and decreased seed weight.

From limited information on *B. campestris*, it appears that it responds to population stress in the same manner as *B. napus*. Overall, *B. campestris* tends to have more branching and more pods than *B. napus* but fewer seeds per pod and a lower 1000-seed weight. Similar observations were made by Morrison *et al.* (1990).

The literature dealing with the effect of row spacing on the components of *Brassica* yield is sparse. Clarke *et al.* (1978b) found that broadcast-seeded *B. napus* cv Tower had more branches per plant and more pods per plant than rapeseed seeded at the same rate drilled in 30-cm rows. The seeding method did not affect the number of seeds per pod or the 1000-seed weight.

Mahasi (1986) reported that row spacing alone had no effect on branching, pod production, seeds per pod, or 1000-seed weight for several *B. campestris* and *B. napus* varieties grown in Edmonton.

2.2.4.3 Effect of Crop Density on Crop-Weed Growth

2.2.4.3.1 Seeding Rate and Row Spacing

Effective use of competition by crop plants is an integral part of weed control strategy. High crop seed rate as a cultural method of weed control has been used for some time. Godel (1935) observed that yield loss was less when wheat was seeded at heavier than normal rates in weedy Saskatchewan fields. The weedy wheat crop had fewer tillers and shorter heads.

Optimum crop seeding rates under weed-free conditions are not necessarily the best seeding rates when weeds are present. Radford *et al.* (1980) observed that the optimum wheat plant density for grain production was higher when wild oats (*Avena fatua* L.) were present than when they were absent. A similar observation was made by Håkansson (1986) for dry matter production by barley, wheat and white mustard (*Sinapis alba* L.) when grown in mixtures or pure stands at various planting densities.

The response of crop plants to weed competition may be similar at various plant densities. Lawson (1982) found that weeds interfered with the vegetative development of peas (*Pisum sativum* L.) mainly at low crop densities where the presence of weeds reduced branching. At higher crop densities, the effect of weeds was smaller as inter-plant competition became the most important factor during vegetative development.

Weeds may affect reproductive growth more severely than vegetative growth. Pea plants had fewer pods per plant and more unfilled pods when grown under weedy conditions. The numbers of peas per pod and individual pea weights were unaffected by the presence of weeds. Weeds reduced total pea yield and the number of pods by a constant amount across the range of pea densities tested (Lawson, 1982). A similar effect was observed by Pfeiffer and Holmes (1961) for a barley crop infested with cultivated oats (*Avena sativa* L.).

Information on the interaction of rapeseed planted at different densities with other plants is scarce. From work on the effect of plant population and spatial arrangement on intercropped wheat and *B. juncea*, Sharma *et al.* (1986) reported that increasing populations of *B. juncea* in any sowing method decreased wheat grain yield.

In general, weed dry weight declines as crop density increases. Radford *et al.* (1980) observed that wild oat dry weight decreased inversely with wheat seeding rate until the wheat population was over 150 plants/m^2. Håkansson (1986) made similar observations but also noted that the reduction in weed dry weight was more pronounced at lower weed densities.

It is agreed that total dry weight values may give a better estimate of how weeds and crops interact in a mixture than plant density. Lawson and Topham (1985) found that there was little variability unaccounted for when simple linear regression was used to describe the relationship between log weed dry weight and pea density. They calculated a weed reduction factor based on the slope to assess the weed dry weight reduction caused by an increase of one crop plant/m^2. Despite different weed densities and species, the reduction factor was relatively constant over sampling times and experiments.

Increased crop seeding rates may not only reduce the amount of dry matter produced by weeds but also their reproductive output. Radford *et al.* (1980) observed that the number of wild oat panicles per plant, spikelets per panicle and seeds declined as the wheat density increased. Increasing the seeding rate of barley reduced the number of tame oat panicles per unit area and the number of spikelets per panicle (Pfeiffer and Holmes, 1961).

Increased crop density has been found to reduce the number of weed species in the field. Lawson and Topham (1985) reported that the number of weed species declined as pea density increased and as the season progressed. There is conflicting evidence as to whether crop density affects the number and evenness of the weeds community as measured by diversity indices (Topham and Lawson, 1982; Lawson and Topham, 1985).

In agricultural systems, plant distribution depends on row spacing and seed distribution within the row. Håkansson (1986) found that weed dry weight was reduced when plants were more evenly distributed within rows and when row spacing was reduced. Theoretically, available plant space should be utilized most efficiently when spacing between the rows equals the spacing within the crop row. Results from a number of trials conducted in Sweden (Andersson, 1986) suggest that optimal row spacing for small-grained cereals may be larger than this theoretical optimum.

Medd *et al.* (1985) could not find any advantage in sowing wheat in set geometrical arrangements for Wimmera ryegrass control. However they did find the effect of ryegrass reduced when the wheat seeding rate was increased. This contrasts with the results of Rerkasem *et al.* (1980) who concluded, based on replacement experiments, that increased wheat density did little to overcome ryegrass competition.

These conflicting observations support Håkansson's (1986) statement that "yield reduction caused by a weed species or a mixed population of weed species is expected to be highly conditional". Yield responses are a product of density, spatial arrangement, species, and environmental, chemical, and physical conditions.

3.0 Weed Factors Involved in the Weed-Crop Competition Process

3.1 Weed Genotype

Within any plant community, each weed may differ greatly in competitive ability. The work of Pavlychenko and Harrington (1934) illustrated the ability of a number of weeds to compete with crop plants under one set of environmental conditions. There are occasions when crops that are grown in one year become weed problems in successive years. This often occurs when crops are swathed late, or if crops lie in swaths for extended periods of time due to unfavorable weather conditions at harvest or when combines are poorly adjusted. Like other weeds, volunteer crops rob the producer of yield. Unlike other weeds, however, the volunteer crop has potential value.

3.1.2 The 'Morphophysiology' of Barley

Barley growth can be divided into three main developmental phases. These are: 1/ establishment to just after the double ridge stage of spike initiation; 2/ from the double ridge stage to anthesis; and 3/ grain growth from anthesis to maturity (Willey and Holliday, 1971).

A barley embryo in a resting seed is comprised of few structures. The coleoptile and first leaf are present, as are the primordia for the second and third leaves. The shoot apex and a tiller bud in the axil of the coleoptile complete the embryonic structure (Bonnett, 1966). The shoot apex resumes growth once the seed is imbibed and germination occurs. During the first six days from the beginning of germination, cereal seedlings depend on the food reserves of the grain for growth. The seedling then becomes progressively more self-supporting, although it may continue to draw reserves from the seed for several more days (Langer, 1967). Seeding to emergence of the first leaf requires approximately seven days at Lacombe, Alberta (Dew, 1980). Depending on the genotype, between seven and 15 leaf primordia are initiated (Wych *et al.*, 1985). The duration and rate of leaf initiation in barley are variable. Kitchen and Rasmusson (1983) found that the duration of the leaf initiation phase in 10 barley cultivars ranged from 5 to 13 days. Increasing light intensity and temperature increased the rates of primordium initiation, leaf emergence and expansion (Langer, 1967). Generally the rate of leaf initiation is approximately two and a half times the leaf appearance rate (Wych *et al.*, 1985). The rate of leaf appearance is closely correlated with the rate of change of daylength at plant emergence (Ellis and Russell, 1984). Dew (1980) reported that Galt barley required approximately 34 days to arrive at the six-leaf stage. It is unlikely that competition from other plants would alter the number of leaf primordia initiated as there is little evidence that cereal primordia compete for assimilates or mineral nutrients (Langer, 1967).

The rate of primordium initiation increases three-fold when the shoot apex moves from the vegetative to the reproductive phase (Gallagher and Biscoe, 1978a). Rather than producing leaves, the primordia will develop into spikelets. The spike initiation period may last seven to 12 days (Kitchen and Rasmusson, 1983), generally between the time the second and seventh leaves on the main stem have unfolded (Gallagher and Biscoe, 1978a). Double ridges are evident about two days after spike initiation (Kitchen and Rasmusson, 1983). One-third to one-half of the spikelets have been initiated at this time (Wych *et al.*, 1985). Primordia continue to form after the double ridge stage until awn primordia are formed on the most advanced spikelets. Depending on the barley cultivar and environment, the number of rachis nodes where the spikelet primordia are initiated ranges from 10 to 45 (Wych *et al.*, 1985). Plants develop approximately two rachis nodes per day (Kitchen and Rasmusson, 1983).

Moisture stress and short photoperiods have been found to reduce the rate of formation of primordia and their development into spikelets. A shorter day may increase the number of spikelets but moisture stress reduces spikelet number (Langer, 1967).

Plant population density also affects spikelet numbers. Barley spikelet number increased in proportion to plant population up to approximately 500 plants/m^2, and declined at plant populations above this level (Willey and Holliday, 1971). Wych *et al.* (1985) stated that plant density does not affect overall spikelet initiation but reduces the duration of initiation. Spikelet survival is also greatest at low plant densities.

Cereal plants grown under low light had more primordia initially. However, the spikelets developed more slowly and over a shorter period of time. The result of reduced light was shorter spikes with fewer spikelets (Langer, 1967). Shading of barley plants due to dense crop stands or by weeds during the spikelet initiation phase could result in a sink (site of carbohydrate utilization) limitation later on due to smaller spikes.

Axillary shoots or tillers are formed at the same time the main shoot is developing. Tillers arise from axillary buds at the bases of leaf sheaths and their development follows the same sequence as that of the main shoot (Friend, 1965). Although the developmental pattern is similar, the time spent in the leaf initiation phase is shorter so that tillers have fewer leaves than the main shoot. This assures that initiation and flowering of the tillers will occur at the same time as the main shoot (Wych *et al.*, 1985).

Not all axillary buds will develop tillers and not all tillers that are produced survive until maturity. Simmons *et al.* (1982) found that tillering capacity varied among barley genotypes. Primary tillers formed most frequently in the axils of the first and second true leaves. Genotypes with high tillering capacity also initiated tillers at the coleoptile node and at the axil of the third leaf. A high tillering capacity did not mean that these tillers were maintained until maturity. In fact, shoot mortality was usually greater in barley with high tillering capacities.

Tiller emergence does not necessarily mean tiller survival. Late-forming and emerging tillers frequently die before maturity (Cannell, 1969). Tiller death may be due to altered assimilate partitioning. A shift in assimilate partitioning away from the tillers and to the main stem and inflorescence 25 to 30 days after emergence has been observed. Tiller count also peaked 25 to 30 days after emergence and then declined (Wych *et al.*, 1985). It was once thought that increased shading of young tillers by the developing crop canopy was responsible for the decline in tiller number. Lauer and Simmons (1989) observed that the rate of leaf appearance on non-surviving tillers declined before the crop canopy developed to the state where shading was great enough to cause senescence. The authors stated that tiller senescence began 19 days after emergence or earlier for some tillers.

Shade has been associated with reduced spike number at harvest. Willey and Holliday (1971) found that barley yield was reduced in plants that were shaded (72% and 46% of the incident radiation) from emergence to the double ridge stage. The authors attributed the reduction in yield to a decrease in the initial production of tillers which resulted in fewer spikes/m^2. Simmons *et al.* (1982) observed large increases in barley tiller mortality when crop row spacing was narrowed from 30 to 15 cm. The higher tiller mortality in narrow rows supported the hypothesis that available light (as it relates to assimilate production) plays an important role in tiller abortion.

Shading by a plant canopy not only reduces the quantity of light available for plant growth but also changes the light quality. Light reaching the lower canopy has a reduced red light component, which results in a lower red to far-red light ratio. Based on observations of reduced tillering in dense grass stands, Casal *et al.* (1986) hypothesized that tillering responds to the changes in light quality before light quantity becomes limiting. This allows the grass to respond to density, by limiting tiller development, before energy reserves are committed to a tiller that will not survive to maturity.

Kirby and Jones (1977) found that removing barley tillers resulted in a main shoot that was heavier and produced more grain per spike because the spike had more and heavier seeds. From their observations they concluded that tillers that die at an early stage were wasteful as they required assimilates for their production but didn't contribute to final grain yield. More recently, translocation experiments using $^{14}CO_2$

have shown that non-surviving tillers transfer more photoassimilate to the main shoot than surviving tillers (Lauer and Simmons, 1988). Non-surviving primary tillers produced in the axils of the first and second true leaves retained only 20% of their fixed radioactivity, lost 30% due to respiration and exported the other 50% (Chafai-Elalaoui and Simmons, 1988).

Leaf assimilate partitioning in tillers that survive to harvest is similar to the pattern observed in the main shoot. Up to 22 days after emergence, tiller leaves are strong sinks for photoassimilate. By 30 days after emergence, the first three tiller leaves provide assimilate for the growth of expanding leaves and the stem in approximately the same proportion. The stem then becomes a major sink for assimilate exported by the second to the sixth leaf. By 38 days after plant emergence, the tiller inflorescence becomes the predominant photoassimlate sink. At the same time the tiller leaves and stem are developing (approximately 30 to 38 days after emergence), the elongating stem of the main shoot is receiving 16 to 43% of the assimilate exported from the tillers. Even after the main stem has elongated, tiller leaves continue to send a large percentage of their exported assimilate to the main shoot. A very small proportion of the label is translocated to adjacent tillers.

Clearly, the time of tiller initiation is a 'critical period' in barley development. Environmental stresses such as high plant population can affect final seed yield by limiting the first component of yield, spike number, very soon after plant emergence.

The first and second phases of barley development overlap when double ridge formation is chosen as the division point. The shoot apex will initiate spikelet primordia after double ridges are formed. Kirby *et al.* (1985) noted that the beginning of stem growth is closely associated with shoot apex development. Elongation of the first internode generally gives a good indication that spikelet formation has stopped. The completion of spike initiation constitutes the very early part of this growth phase. Development of the differentiated spike and elongation of the stem (jointing) comprise the bulk of this stage.

Spike initiation, on average, is complete 20 days after plant emergence. Spike growth will continue for another 20 days, so that the vegetative period of growth lasts approximately 40 days (Kitchen and Rasmusson, 1983). This stem growth affects barley yield in several ways.

During stem elongation, stems accumulate assimilate produced by the leaves that could be used for tiller and spike growth. Lauer and Simmons (1985) reported that stem growth began to increase 19 to 28 days after emergence. At approximately 35 days after emergence, stem dry matter accumulation was linear. The stem received assimilate preferentially from leaves four through nine. The amount of carbon partitioned into the stem varied with stem growth. As stem development advanced, the proportion of photoassimilate coming from leaves three to five increased. Competition between the stem and the tillers between 19 and 34 days after emergence was thought to play a role in premature tiller mortality. By acting as an alternate sink, stem development may sacrifice seed yield by drawing photoassimilate away from the developing spike and tillers.

Willey and Holliday (1971) found that shading during the barley spike development and stem elongation phase resulted in large reductions in barley grain yield. This was a result of reductions in yield components (spike number, seed weight), with the number of seeds per spike being particularly sensitive to a reduction in photoassimilate.

Barley yield has been found to be strongly correlated with the number of seeds/m^2 rather than with seed weight. This yield component is set by the time anthesis occurs and has been found to be related to crop dry weight at that time (Russell and Ellis, 1988). As the rate of cereal crop growth is proportional to the rate of PAR (photosynthetically active radiation) (Gallagher and Biscoe, 1978b), absorption and reduction in light available during the stem development phase could impinge on final seed yield.

Fisher and Stockman (1980) observed that wheat plants were most sensitive to shading 10 to 13 days before anthesis. Shading reduced overall dry matter accumulation. The reduction in photoassimilate at this critical time limited the number of florets that developed fully and the overall spike dry weight at anthesis. The consequence was that the potential final seed yield was affected by the reduction of a second component of seed yield, seeds per spike, prior to anthesis.

Environmental variables such as daylength and temperature will also affect barley floret number and fertility. Guitard (1960) found that increasing the temperature from 13 to 24 C reduced the number of florets per spike. Increasing the daylength also reduced floret number (Guitard, 1960; Tingle *et al.*, 1970). Temperature is known to be critical during the pollen formation phase of inflorescence development (Evans and Wardlaw, 1976). Tingle *et al.* (1970) noted that pollen fertility decreased under very long day and very short day conditions. Percent fertility was highest when the plants grew at 18 C.

A second function of the stem is to act as a source of carbohydrates and nitrogenous compounds that can be mobilized and translocated to kernels during grain filling. Any environmental stress that restricts the accumulation of this material could affect final seed yield. Estimates of the contribution of the stem to final seed yield have been variable. This may be due to the fact that the size of the sink can regulate both the production and movement of photoassimilate within the plant (Langer, 1967). The contribution of pre-anthesis assimilate to final grain yield has been estimated at between 11 and 44%. The contribution may depend on growing conditions. Stress, such as drought, during grain filling will reduce current photosynthate supply so the plant will depend more on mobilized carbohydrate and nitrogenous compounds that have been stored in the stem when conditions were better (Wych *et al.*, 1985). If the plant population is high, perhaps due to weeds, barley plants could also draw on stem reserves. If stem dry matter has been reduced already due to plant density, grain yield would no doubt be limited.

The third function of the stem is structural support. Stem strength affects lodging and ultimate final seed yield if the crop can't be swathed or combined properly.

Anthesis marks the end of the second developmental phase and the beginning of the grain growth and maturity phase. The potential number of seeds has been set even before anthesis by the number of spikelets that have developed. Not all spikelets will contain a fertile floret. By anthesis up to 40% of the spikelets may have died (Gallagher and Biscoe, 1978a). The pollen and ovules of each of the florets mature at the same time (Reid, 1985), which generally ensures self-pollination of the crop. Fertilization can have taken place even before the spikes have fully emerged. This usually occurs when temperatures have been high (Poehlman, 1979 p. 227).

The setting of seed after anthesis is another 'sensitive' period in barley development. Low light, high temperature, or water stress are known to reduce seed set in barley and wheat (Evans and Wardlaw, 1976; Langer, 1967). Under average conditions, approximately 95% of the spikelets that are fertile at anthesis will produce harvestable seed (Gallagher and Biscoe, 1978a).

Barley grain growth exhibits the typical sigmoidal pattern observed in other cereals. Initially there is a slow growth phase (lag phase), which lasts seven to 14 days, during which the cells are dividing rapidly (Gallagher and Biscoe, 1978a). A longer lag period may allow later developing florets to set grain (Evans and Wardlaw, 1976). Bingham (1965) stated that final grain weight was dependent on grain weight measured shortly after anthesis. The ultimate sink capacity of the seed is determined by the number of endosperm cells laid down in the two weeks following anthesis. Endosperm cell number is dependent on assimilate supply (Brocklehurst, 1977). Usually by the end of the lag phase the seed is approximately 15% of its final weight. Assimilate requirements during this phase are modest (Evans and Wardlaw, 1976), but a limitation of assimilate at this time may result in lighter seeds (Gallagher and Biscoe, 1978a).

Following the lag phase, grain weight increases at a steady rate. This is known as the linear phase of growth (Evans and Wardlaw, 1976). Final seed yield is determined by a balance between grain growth rate and grain growth duration. In barley, maximum kernel growth rates range from 0.9 to 2.2 mg/kernel/day (Wych *et al.*, 1985). The rate of growth per kernel increases with temperature while duration of grain growth is shortened (Evans and Wardlaw, 1976). Controlled environment experiments have shown that high temperatures reduced grain growth duration proportionally more than grain growth rate (Gallagher and Biscoe, 1978a).

The effect of light on the rate of grain growth is not well documented. The situation is complicated by mobilization of stem reserves. Evans and Wardlaw (1976) stated that the rate of growth per kernel was not limited by assimilate supply except under conditions of very low light.

Percentage moisture of the seed declines as filling occurs. This is not an actual loss of water but a dilution effect due to the gain in dry matter (Meridith and Jenkins, 1975). Once the vasculature connecting the seed to the rest of the plant has collapsed, water lost is by evaporation. The rate of loss is dependent on environmental factors and seed characteristics (Troyer and Ambrose, 1971).

During the third phase, grain growth rate slows until there is no further increase in grain weight. The causes of grain growth cessation are not clear. Lingle and Chevalier (1985) thought that it was not due to anatomical changes. The collapse of the vasculature to barley and wheat seeds was a result of, not the cause of, the decline in the rate of dry matter accumulation they observed. Evidence from wheat suggests that grain growth does not stop due to a lack of assimilates (Evans and Wardlaw, 1976). It has been suggested that a decline in the activity of starch synthesizing enzymes brings about the end of grain filling (Gallagher and Biscoe, 1978a).

Kernel weight is considered to be a relatively stable component of barley yield (Wych *et al.*, 1985). Within any spike, the weight of the seeds will vary with floret position. In barley, the heaviest kernels are located in the centre of the spike. This is where floret development begins. The gradient of seed size is associated with differences in floret initiation, development and ovary growth (Gallagher and Biscoe, 1978a). There is no evidence that assimilate supply is related to position on the spike. In defoliation experiments where total assimilate supply was reduced, the reduction in seed weight was the same irrespective of seed position (Gallagher and Biscoe, 1978a).

Investigations into the translocation of assimilates have shown that the carbohydrate incorporated into grain is derived mainly from current assimilate derived from leaf and spike. The role of the stem as a source of carbohydrate for grain filling was discussed earlier.

Carbon that is assimilated by the flag leaf moves predominantly to the grain. There is evidence that the photosynthetic rate of leaves can respond to changes in demand for assimilates. Shading of barley spikes was found to double the flag leaf photosynthetic rate and increase the proportion of assimilates going to the ear from 51 to 86%. Changes in potential sinks for assimilates will determine assimilate distribution. If the upper leaves are shaded or removed, assimilate from lower leaves will then support grain growth (Evans and Wardlaw, 1976).

In barley, spike photosynthesis can comprise 25 to 50% of total crop photosynthesis, and is responsible for 24 to 84% of the grain growth. Awns increase the photosynthetic area of the spike. Three-quarters of the barley spike transpiration and photosynthesis can be attributed to the awns (Evans and Wardlaw, 1976).

A reduction in current photosynthate during barley grain filling may not always translate into reduced seed yield. Willey and Holliday (1971) shaded barley plants from anthesis to maturity and did not find any reduction in grain yield. This highlights the importance of carbohydrate accumulation prior to anthesis and its role in yield formation under conditions of stress.

In summary, there are a number of 'critical' periods during the development of barley where stress imposed at the time will reduce final seed yield. Stress could be imposed by high temperature or a reduction in moisture or light due to high plant populations. For the most part, the organ that is growing most rapidly at the time the stress is imposed is the one that is most affected. In pre-anthesis growth, tillering and floret initiation are particularly sensitive to environmental stress that will affect the number of units produced. At anthesis, temperature may affect pollen fertility. After anthesis, a reduction in assimilate during the lag period will reduce the number of endosperm cells laid down in the seed. Finally, the availability of photoassimilate during the entire growth cycle appears to be integral to final seed yield.

3.2 Weed Density

Growers need to know the impact of weeds on crop yield to determine the most cost-beneficial weed control programme possible. There are numerous reports in the literature on yield loss caused by various densities of weeds. In the past, most researchers have assumed there is a minimum weed density at which crop yield is not reduced and also a maximum weed density above which there is no further loss in yield. This relationship is described by a sigmoidal curve (Zimdahl, 1980 p. 29). Dew (1972) was one of the first weed scientists to use regression analysis to quantify this relationship. These types of equations usually fit the data well when yield on an area basis is used. The equations have been used to develop economic threshold levels for weeds to provide a basis for farmers to decide if weed control is warranted. Regression equations will not provide a measurement of growth factors involved in competition, but they will indicate density relationships and the degree of competition (Aldrich, 1987). A limitation in using regression analysis arises when yield is presented as yield loss based on the weed-free crop yield. The regression line is usually not constrained to pass through the origin, therefore yield losses or gains may be predicted when no weeds are present (O'Donovan *et al.*, 1988).

More recently, Cousens (1985) has suggested that a rectangular hyperbola best describes the relationship that exists between weed density and percentage reduction in crop yield. This approach implies there is no minimum number of weeds tolerable in a crop. One advantage of this approach is that no yield loss is predicted when the weed density is zero. This type of model can also be used to give predictions for situations not covered by the experiment. A weakness in Cousens' approach is that in a row crop, the spatial arrangement is such that it is likely that some minimum number of weeds can be present without any interference between the weeds and the crop (Aldrich, 1987). A second consideration is that, while hyperbolic models may be more biologically sound, they have not been shown to fit percent yield loss data any better than the less complicated regression equations (Cousens *et al.*, 1987). The method of analysis of weed density-crop yield data appears to be dependent on the objectives of the researcher.

Overall plant density is increased when weed populations are increased in a crop seeded at one specific rate. Although there may be two or more components in the plant community, the responses of both the weeds and the crop to the stress imposed by increased density are similar to those outlined previously for crops grown alone at different populations. In general, plants respond to increased stress imposed by density by plastic responses. There may also be death of individual plant parts or of the whole plant (Harper, 1977 p. 152). The result of the altered physiological and morphological state due to plant density is a plant population made up of individuals of varying sizes. Robust plants appear to grow unhindered while the growth of smaller or weaker members of the mixture is suppressed (Glauninger and Holzner, 1982).

The amount of crop yield lost due to different densities of weeds will depend on the crop and weed species, climate and agricultural factors such as fertility (Glauninger and Holzner, 1982). Several examples illustrating these points can be drawn from research conducted in western Canada and elsewhere.

Some of the earliest weed competition work was conducted by Pavlychenko and Harrington (1934) in Saskatchewan. They conducted experiments to determine the relative competitive efficiencies of weeds and crops based on their rates of growth, germination characteristics, photoassimilatory surface area and root development. It was shown that readiness and uniformity of germination, early development of leaf area and a large root system were features of the more competitive plants they examined. Crops were classified according to their competitive power as follows: barley>rye (*Secale cereale* L.)>wheat=oats>flax (*Linum usitatissimum* L.). Of the 11 annual weed species examined, wild oats and wild mustard were identified as the most competitive.

This order of crop competitiveness was confirmed by Dew (1972, 1976) for crops grown with different densities of wild oats at Lacombe, Alberta. He reported the following indices of competition (competitiveness declines as the number increases), barley 2.3, rapeseed 3.2, wheat 3.4 and flax 6.0. O'Sullivan *et al.* (1982, 1985) observed that rapeseed and barley yield loss was proportional to Canada thistle shoot density. They suggested that Canada thistle (*Cirsium arvense* (L.) Scop.) was three times as competitive as wild oats. Based on the competitive indices formulated by Dew (1972), the indices of competition were 7.6 for barley and 10.4 for rapeseed competing with Canada thistle. They estimated that they would be 19.8 in flax and 11.2 in wheat.

Burrows and Olson (1955a, 1955b) reported that yield of wheat and flax declined with increasing wild mustard density. Dry matter production by wheat and flax declined as wild mustard density increased. Wild mustard reduced tillering in wheat and basal branching in flax.

Wheat and flax yield declined as wild oat density increased (Bowden and Friesen, 1967). The yield of wheat grown on summer-fallow was reduced by a wild oat population of 10 to 40 plants/m^2, while only 10 wild oat plants/m^2 were sufficient to reduce flax yield. Soil fertility affected the way in which wheat responded to wild oat density. The reduction in wheat yield due to wild oats was similar whether wheat was grown on summer-fallow or on fertilized stubble. When grown on unfertilized stubble, wheat yield was not reduced until there were 70 to 100 wild oat plants/m^2 present in the crop. The authors suggested that in unfertilized stubble, soil fertility was a more important factor than moderate wild oat density in determining crop yields.

Experiments conducted in Manitoba have shown that the average wheat yield loss due to weed competition was 21% in unfertilized portions of fields compared to 12% in fertilized portions of the same fields (Nakoneshny and Friesen, 1961). Fertilizer application may prove beneficial in increased crop production, but it may be at the expense of increased weed growth. Sexsmith and Russell (1963) reported that phosphorus fertilizer had no measurable effect on the number, height, straw weight or seed weight of wild oats. However, wild oat plants responded to nitrogen fertilizer additions by increased tillering, plant height, straw and seed production. Carlson and Hill (1985) also evaluated the effects of wild oat density, wheat density and nitrogen fertilization on wheat yield and concluded that wild oats utilized added nitrogen more effectively than wheat and thus gained a competitive advantage. The result of the increased competitiveness was reduced crop yields.

Soil moisture conditions will affect the competitive ability of individual weeds. The response to moisture by individual weeds may partially explain why weed problems vary in different regions. Wiese and Vandiver (1970) found that barnyard grass (*Echinochloa crusgalli* (L.) Beauv.), cocklebur and large crabgrass (*Digitaria sanguinalis* (L.) Scop.) produced vigorous growth and were serious competitors when soil moisture was adequate. This was used to explain why these weeds were problems in humid or irrigated farming areas. Kochia (*Kochia scoparia* (L.) Schrad.) and

Russian thistle (*Salsola kali* L. var. *tenuifolia* Tauch) produced more dry matter under dry soil moisture conditions than under medium or wet soil moisture regimes. These weeds are major problems in semi-arid and arid regions.

Perennial weeds also cause serious losses in yield. Anderson (1956) reported that various perennial weeds resulted in the following yield losses in oats: quackgrass (*Agropyron repens* (L.) Beauv. = *Elytrigia repens* (L.) Nevski) 67%, perennial sow thistle (*Sonchus arvensis* L.) 58%, Canada thistle 40%, toadflax (*Linaria vulgaris* Mill.) 28%, bladder campion (*Silene vulgaris* (Moench) Garcke) 11%. A Canada thistle or perennial sowthistle patch with a shoot density of 10/m^2 would reduce rapeseed yield by 14 and 40%, respectively (O'Sullivan *et al.*, 1985; Peschken *et al.*, 1983).

Few researchers in western Canada have documented the effect of various densities of annual weeds on rapeseed yield. Malik and Vanden Born (1985) reported that a dense false cleavers (*Galium spurium* L.) stand (100 plants/m^2) reduced rapeseed yield 20% when left in the crop the entire season. There were no significant reductions in rapeseed yield when cleavers were present in moderate numbers (5 to 50 plants/m^2); however, a light infestation of only 5 plants/m^2 resulted in a contamination level of five cleavers seeds per gram of rapeseed harvested. In 1983, a hemp-nettle (*Galeopsis tetrahit* L.) density of 130 plants/m^2 was required to reduce the yield of Tobin canola (de St. Remy and O'Sullivan, 1983). Based on the prediction equation developed by Dew (1976), rapeseed yield was reduced approximately 3% for each wild oat/m^2 present in the crop. From the scant information available, it appears that grass weeds have the potential to reduce rapeseed yield more than broad-leaved weed species.

In canola producing areas of Alberta, canola frequently follows barley in rotation. Volunteer barley thus has the potential to act as a grassy weed in the following canola crop.

Recently, volunteer barley was found in 14% of all wheat, oat and canola fields surveyed in central Alberta (Pickle, 1989, pers. comm.). Information dealing with yield loss due to various densities of volunteer cereals in rapeseed is limited.

Marshall *et al.* (1989) seeded wheat and barley as volunteer weeds and canola (*B. napus*) in Manitoba. Linear regression was used to describe the relationship between biomass or seed yield (g/m^2) and cereal density. Only the barley decreased rapeseed biomass as the cereal density increased. Thirty barley plants/m^2 reduced rapeseed biomass by approximately 19% and seed yield by 27% in 1982 and 35% in 1983. A similar density of wheat reduced rapeseed yield by approximately 17% in both years. As rapeseed yield declined, the seed yield of the cereals increased. As the cereal density increased, barley yield increased to a proportionally greater extent than wheat yield. Both weed and crop yield were lower in 1983 than in 1982. The authors attribute the yield differences to drought conditions experienced in 1983.

O'Donovan *et al.* (1988) used nonlinear rectangular hyperbola models to describe the relationship between canola (*B. campestris* and *B. napus*) yield loss and 'volunteer' barley density for experiments conducted in Alberta and Saskatchewan from 1982 to 1986. Canola yield loss increased with increasing barley density. When there were few barley plants present, yield loss was nearly proportional to density, but as barley density increased, the yield loss per individual barley plant diminished due to intra-specific competition. At high barley densities of 200 plants/m^2, canola yield was reduced up to 80%. At a moderate barley density of 25 plants/m^2, canola yield was reduced between 10 and 25%. Yield loss due to barley was higher when the canola density was low and where basic rapeseed yield potential due to environmental conditions was high.

3.3 Time of Emergence

"The advantage which an early emerging seedling gains is far greater than can be accounted for merely by the greater time it has been allowed to grow. The advantage must be due, at least in part, to the capture of a disproportionate share of the environmental resources by the individuals that emerge early and a corresponding deprivation of those that emerge late" (Harper, 1977 p.168).

The potential size of an individual plant in a population is determined by the seed size and reserves, rate of growth and length of time plant growth is unrestricted by neighbours (Harper, 1977 p. 161). It is unlikely that weeds growing in a crop will affect the reserves available for establishment contained in the seed (unless they were present when the seed was developing). However, they can affect the rate and duration of growth. The interaction between weed and crop plants will occur sooner if one emerges before the other.

The effect of competition between plants tends to be cumulative. 'Snowball' accumulation is known to occur when plants differ in size when they first start to compete for light rather than nutrients. For example, plants with long petioles grow larger because they garner more of the light resource. The result of this increased growth is a plant with even longer petioles so that the competitive advantage for light is increased (Wilson, 1988). This same scenario could occur in a crop-weed situation where an early emerging weed develops a leaf canopy before the crop and thus limits crop dry matter production. Alternatively, a crop might eliminate late emerging weeds by the same process.

Experiments reported in the literature rarely examine the processes by which crop yield is limited by early emerging weeds. Peters and Wilson (1983) observed that wild oat plants emerging at an early stage of spring barley growth caused a greater crop yield loss than the same density of wild oats emerging later. The wild oat plants that emerged before the crop produced five times more seeds per plant than wild oat plants that emerged when the barley was in the two to three-leaf stage. The panicles of early emerging wild oats were heavier and more numerous than the panicles of wild oats that emerged later.

McBeath *et al.* (1970) reported that in a weed-crop mixture the first species to germinate became "better established" and "more competitive for growth factors". The advantage of first germination continued through the subsequent growth stage. Under growth cabinet conditions, wild oats emerging before the barley crop reduced culm number and dry matter production. The reverse was true for wild oats emerging after the crop. In this case, wild oat panicle number and weight were reduced.

Under Alberta field conditions, early emerging wild oats reduced wheat yield more than barley yield. For each day the weed emerged before the crop the yield loss increased by approximately three percent. The magnitude of yield loss was dependent on the wild oat density as well as time of emergence (O'Donovan *et al.* 1985; Cousens *et al.*, 1987).

Early crop emergence has been used as a method of weed control for a long time. Thurston (1962) demonstrated fall-seeded cereals (winter wheat, winter rye, winter barley) were better at limiting the spring growth of wild oat than spring-seeded barley. Effective wild oat control was dependent on density of the winter crop when the weed emerged rather rather than on crop genotype.

There are few reports of time of emergence experiments in which the effect of early emerging weeds in broad-leaved crops was examined. Williams (1964) is the only researcher who examined the effect of weed emergence time in a *Brassica* crop (to the author's knowledge). Kale (*Brassica oleracea* L.) and lamb's-quarters (*Chenopodium album* L.) were seeded in equal mixtures 14 days before, at the same time, or 14 days after each other at densities of 100 or 400 plants/m^2. Planting kale two weeks before the lamb's-quarters resulted in high plant mortality of the kale. When the kale emerged before the weed, the lamb's-quarters growth was reduced but the plants survived to produce some seed. Even when the kale emerged before or at the same time as the weed, kale plant height was reduced. When the crop and weed were planted at the same time, internode lengths of plants in the mixture were greater than lengths in pure stands of the crop or weed. Lamb's-quarters had longer internodes even when it emerged after the crop. This is a feature of lamb's-quarters growth that allows the weed to avoid shading. Kale dry weight was reduced by lamb's-quarters emerging 14 days before or at the same time as the crop. It was not until the lamb's-quarters emerged 14 days after the crop that the kale weight was similar to the dry matter produced by weed-free kale. The difference in dry weight was likely due to the fact that kale plants grown with lamb's-quarters had a lower leaf area and a shorter leaf area duration than those in weed-free stands. The lamb's-quarters produced and maintained leaves longer even when the kale emerged 14 days before the crop. It was apparent from these results that the advantages gained by early emergence were maintained by the species that emerged first and increased over time.

3.4 Time of Weed Removal

The time at which weeds are removed from crops is almost as important as the weed removal itself. The competitive interaction between weed and crop does not begin until they start to vie for the same resource. There are, then, periods during the development of the crop when weed presence may not be damaging to final seed yield. The 'critical period' is the length of time weeds can remain in the crop before crop yield will be affected or the point after which further weed growth will not affect final crop yield (Zimdahl, 1980 p. 83).

Timeliness of weed control is essential for herbicide efficacy. Producers need to apply herbicides before measurable crop loss attributable to weed competition occurs (Chancellor and Peters, 1974). The critical periods for weed removal vary with the crop grown, weed type and density, and environmental conditions (Glauninger and Holzner, 1982).

There is a wide range of time that weeds may be present in crops before yield is impaired. Bowden and Friesen (1967) suggested that wild oats began interfering with wheat growth prior to emergence, while Gillespie and Miller (1984) reported that volunteer sunflower (*Helianthus annus* L.) could remain in wheat until the flag-leaf stage without any significant yield loss.

The yield lost for the time a weed remains in the crop will vary with crop genotype. Tartary buckwheat (*Fagopyrum tataricum* (L.) Gaertn.) reduced yield between 0.4 and 1.1% for each day it remained in two oilseed and three cereal crops grown at Lacombe, Alberta. The order of percent yield loss, from the largest to smallest, was flax>oats>wheat>barley>rapeseed (de St. Remy and O'Sullivan, 1986).

Results comparing the effect of different weed species on the same crop plant in the same environment are scarce. Data for Tartary buckwheat and wild oats grown at Lacombe, Alberta in 1977 showed that wild oats were more competitive than Tartary buckwheat. Wild oats left in wheat and rapeseed for 29 days after plant emergence resulted in yield losses of 20% and 19%, respectively. Tartary buckwheat competition for approximately 30 days reduced wheat yield by 2% and rapeseed yield by 10% (Dew, 1977a, 1977b, 1977c, 1977d).

There are few reports on the effect of duration of weed competition on rapeseed/canola yield. Garcia Torres and Vasquez Cobo (1981) grew spring-type rapeseed under weedy conditions in Spain. Weed-crop competition for 6, 10 or 12 weeks after emergence reduced crop yield by 13, 25 and 32% respectively. Rapeseed yield loss due to season-long competition from a variety of weeds averaged 28% for 12 experiments.

No reports on the time of barley removal from rapeseed/canola originating in North America are known to the author. British results on the effect of volunteer cereal competition on winter rapeseed yield have not been conclusive. Rapeseed yield was not reduced by a mixed population of weeds present at densities greater than 200 plants/m^2. However, volunteer cereals and other annual grasses exceeding 70 plants/m^2 were more competitive than broad-leaved weed species in reducing spring growth of a winter rapeseed crop (Lutman, 1984).

In a series of experiments on the effect of volunteer barley competition on winter rapeseed yield, Lutman and Dixon (1986) observed that the yield of winter rapeseed planted late in August was not reduced by winter barley populations up to 285 plants/m^2. However, when the crop was sown in mid-September, yield was affected by barley populations over 100 plants/m^2. Even when fall growth of the rapeseed was reduced by 70% due to barley competition, the crop recovered in the spring and yield was not affected if the cereal was controlled by a herbicide applied in November. The authors concluded that spraying rapeseed crops in September or early October to prevent volunteer barley competition was not necessary.

In experiments where weeds were removed from the crop at various intervals, there was little evidence that early weed eradication resulted in higher crop yield. Orson (1984) examined the timing of herbicide application for volunteer winter cereal control and found that when the winter rapeseed crop was growing vigorously, the time of cereal removal had little effect on final seed yield. However, in one experiment a 21% advantage in yield was observed when winter barley was controlled with fluazifop-butyl[4] at the two to three-leaf stage rather than two weeks later at the tillering stage.

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[4] (±)-2-[4-[[5-(trifluormethyl)-2-pyridinyl]oxy]phenoxy]propanoic acid

CHAPTER 1

COMPETITION BETWEEN BRASSICAS WITH DIFFERENT GENOTYPES AND BARLEY

INTRODUCTION

Differences in the ability of different crop genera to compete with weeds have been well established (Dew, 1972; de St. Remy and O' Sullivan, 1986). There are several species within the Brassicaceae family that are grown, or have the potential to be grown, as oilseed crops with low glucosinolate and low erucic acid levels. In western Canada, these canola-type oilseeds include *Brassica campestris*, *B. napus* and *B. juncea*. Hybridization of these species and/or the incorporation of herbicide resistance into these *Brassica* species provides an array of cruciferous plants that may have different yielding abilities or show different degrees of competitiveness in the presence of weeds.

Researchers who have studied the competitive ability of various cultivars or lines within a single genus and species have profiled a competitive crop plant as one that is tall, utilizes the whole growing season, and rapidly produces a large amount of vegetative material that is maintained throughout much of the growing season (Staniforth, 1961; Blackshaw *et al.*, 1981; Kawano *et al.*, 1974; Forcella, 1987a). This crop ideotype is not easily obtained in a short-season environment where selecting for early maturity may mean that vegetative growth is sacrificed in order to maximize reproductive development.

A few researchers have tried to correlate botanical traits like plant height, maturity, growth habit and seed size with both intra- and inter-specific competitive ability of individual cultivars. In some instances, plant competitiveness could be correlated with morphological traits, in other cases it could not (Sakai, 1955; Jennings and Aquino, 1968; Kawano *et al.*, 1974).

From research conducted under weed-free conditions it has been possible to associate a number of parameters with *Brassica* seed yield. Yield has been reported to be highly correlated with total plant dry weight in both *B. campestris* and *B. napus* (Thurling, 1974a; Campbell and Kondra, 1978b). The high correlation (r=0.95) of vegetative yield (total weight - seed weight) and seed yield on a per plant basis recorded by Campbell and Kondra (1978b) indicated that for *B. napus*, plant size was a major determinant of seed yield per plant. Should the same principles apply on an area basis, *Brassica* varieties with the highest dry matter production should also have the highest yield.

Campbell and Kondra (1977, 1978a) found that growth characteristics associated with early maturity were also associated with higher seed yield. They observed that time to first flower was a major indicator of early maturity and that advancement of initial growth stages (such as flowering) contributed to the timing of subsequent growth stages. Canadian rapeseed breeding programmes have emphasized early maturity and high yield. While heritability is low, partial dominance for early flowering has been demonstrated (Campbell *et al.*, 1978).

Inter-cropping, compared to mono-cropping, can delay flowering (Francis, 1985). The effect of weeds on the time to flowering has received little attention, especially in short-season environments where delayed flowering may result in reduced yield. If a weed were to delay flowering of late season Brassicas in marginal growing areas, yield would be compromised. If the presence of weeds advanced flowering by shortening the length of time spent in the vegetative stages there could be yield enhancement. The yield increase would no doubt be masked by the yield loss due to the presence of the weed itself.

Harvest index is also an important factor in determining final seed yield. It reflects the capacity of the plant to translocate photosynthate to economically important organs (Thurling, 1974a). Harvest index values, on a per plant basis, in *B. campestris* (Thurling, 1974a) and *B. napus* (Campbell *et al.*, 1978) were highly correlated with rapeseed yield.

The effect of such factors as dry matter production, harvest index *etc.* on yield of *B. napus* and *B. campestris* grown under weed-free conditions has been firmly established. However, the yield response of a wider range of *Brassica* genotypes under weedy conditions has not been explored.

In central Alberta, much of the oilseed *Brassica* is grown in a rotation where rapeseed/canola follows barley. When the barley is removed as grain, barley plants frequently become weed problems in the subsequent year. If the producer were able to select a more competitive *Brassica* species or cultivar, the threshold density at which barley should be removed by chemical means could be raised.

The objective of this research was to assess the competitive ability of the range of *Brassica* types available to producers in western Canada. These included representatives of *B. juncea, B. campestris, B. napus*, hybrid *B. napus*, triazine-tolerant *B. napus* and hybrid triazine-tolerant *B. napus*.

MATERIAL and METHODS

Field procedure. Field experiments were conducted at the Agriculture Canada Research Station, Lacombe, Alberta (52^0 28' latitude, 113^0 44' longitude) in 1985 and 1986. The Brassicas included in the experiment are listed in Table 1. The hybrid *B. napus* and hybrid triazine-tolerant *B. napus* F_1 seed was produced by hand-crossing material in the greenhouse prior to each field season. The cultivar Regent and triazine-tolerant Regent were used as the pod parents. Triazine-tolerance of the triazine-tolerant Regent was assured by post-emergence spraying of the plants at the four to five-leaf stage with atrazine (1.1 kg a.i./ha). Flowers of the triazine-tolerant pod parents were hand-emasculated and bud-pollinated. The crosses were protected from contamination with glassine bags. The plants were grown in a greenhouse between January and April of 1985 and 1986 at a 20/15 C day/night temperature regime. The ambient light was augmented by metal halide fixtures providing an extra 200 $\mu E/m^2/sec$ over a 16 to 18-hour photoperiod. A limited seed supply did not allow seeding of the triazine-tolerant parent in the field in 1985. Seed was increased and triazine-tolerant Regent was included in the 1986 trial.

The field plots were established on weed-free, fallowed Ponoka silt loam soil (26% sand, 34% silt, 40% clay, OM 9% pH 6.0). The experiment was set out in a split-block design. The various Brassicas seeded at a target density of 150 plants/m^2, arranged in a completely randomized design, constituted the whole plots of this experiment. The sub-plot treatments contained *Hordeum vulgare* cv Galt as a weed, seeded at a target density of 75 plants/m^2 or were barley-free. The weedy and weed-free strips were randomized across four replications. In the weed-free portions of the experiment, the seeder used to seed the barley was driven over the plots to assure similar compaction. Due to the limited amount of hand-crossed material, the plots were only 0.9 by 5.5 m. Row spacing was 23 cm. Plant measurements were made on a 0.42-m^2 area which was selected and marked in each plot shortly after plant emergence.

The seedbed was prepared by cultivating two or three times in the spring with a vibrashank cultivator, followed by harrowing with a spike-tooth harrow. The canola and barley were planted to emerge simultaneously with a double-disk press-type drill. The seeding, emergence and harvest dates are listed in Table 2. Flea beetles (*Phyllotreta cruciferae* Goeze, *P. striolata* Fab.) were controlled with a post-emergence application of DECIS 5 EC[1] (deltamethrin 6.2 g a.i./ha). No fertilizer was added in either experiment-year.

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[1] Hoechst Canada Inc., 295 Henderson Dr., Regina, Saskatchewan S4N 6C2

Table 1. Origin of *Brassica* cultivars and lines.

Species	Cultivar/line	Cross	Developed by	Registered	Comments
B. campestris	Tobin	-originates from crosses involving yellow-seeded, low erucic acid, low glucosinolate strains related to cv Candle, low erucic acid strain SV72/10308 and Mexican material with staghead resistance	Agriculture Canada, Research Station, Saskatoon, Saskatchewan	May 1980	-approximately 45% of the seeded acreage on the prairies in 1987
B. juncea	Domo	-selection from a single open-pollinated plant from a broad-based population	Agriculture Canada, Research Station, Saskatoon, Saskatchewan	April 1977	-supplied by Dr. K. Downey, Saskatoon Research Station
	Cutlass	-selection made from Domo	Agriculture Canada, Research Station,	April 1985	-supplied by Dr. K. Downey, Saskatoon Research Station
B. napus	Westar	-selection from an F_4 generation cross((SdxS68-2895)F_3 x Midas)F_2 x Tower	Agriculture Canada Research Station Saskatoon, Saskatchewan	April 1982	-approximately 49% of the seeded acreage on the prairies in 1987
	Regent	-selection from backcrossing Liho to reduce erucic acid and Bronowski to reduce glucosinolates, put into Target and Turret material	University of Manitoba, Winnipeg, Manitoba	March 1977	

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Table 1. (Continued).

Species	Cultivar/line	Cross	Developed by	Registered	Comments
B. napus	Andor	-selection from backcrossing Liho to reduce eruic acid and Bronowski to reduce glucosinolates, put into Target and Turret material	University of Alberta, Edmonton, Alberta	March 1981[†]	-supplied by Dr. Z. Kondra, Plant Science, University of Alberta
	Hanna	-selected from (Bronowski x Oro) x Gulle	Weibullsholm PBI, Landskrona, Sweden	April 1985	-supplied by Dr. W. Beversdorf, Crop Science, University of Guelph
	Topas	-selected from (Bronowski x Gulle) x SV Hermes	Svalof A.B., Svalof, Sweden	April 1987	-supplied by Dr. W. Beversdorf
	Karat				-supplied by Dr. L. Sernyk, Plant Science, University of Manitoba
	SV02231		Svalof A.B., Svalof, Sweden		-supplied by Dr. W, Beversdorf
Triazine-tolerant *B. napus*	OAC Triton	-selection from a backcross of Tower (*B. napus*) and a triazine-tolerant *B. campestris* biotype	University of Guelph, Guelph, Ontario	March 1984	

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Table 1. (Continued).

Species	Cultivar/line	Cross	Developed by	Registered	Comments
Triazine-tolerant *B. napus*	Tribute	-selection from (triazine-tolerant *B. campestris*) x Tower x Altex	Agriculture Canada, Research Station, Saskatoon, Saskatchewan	Nov. 1985	
	OAC Triumph	-backcross of Topas with (OAC Triton x Topas)	University of Guelph, Guelph, Ontario	April 1987	
	Regent	-backcross of Regent with (a triazine-tolerant *B. campestris* biotype x Regent)	University of Manitoba, Winnipeg, Manitoba	March 1977	-supplied by Dr. L. Sernyk
	Line 1	-backcross of Hanna with (OAC Triton x Hanna)	University of Guelph, Guelph, Ontario		-supplied by Dr. W. Beversdorf
	Line 2	-backcross of SV02231 with (OAC Triton x SV02231)	University of Guelph, Guelph, Ontario		-supplied by Dr. W. Beversdorf
Hybrid *B. napus*	Hybrid 1	-hand-cross of Regent x Karat			-made by author
	Hybrid 2	-hand-cross of triazine-tolerant Regent x Karat			-made by author

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† Deregistered in 1988.

Table 2. Seeding, emergence and harvest dates.

Year	Species†	Cultivar/line	Seeding date	Emergence date	Harvest date
1985	*B. campestris*	Tobin	May 21	May 30	Sept. 3
	B. juncea	Cutlass	"	"	Sept. 3
		Domo	"	"	Sept. 3
	B. napus	Andor	"	"	Oct. 1
		Hanna	"	"	Oct. 4
		Karat	"	"	Oct. 1
		Regent	"	"	Oct. 1
		SV02231	"	"	Oct. 4
		Topas	"	"	Oct. 4
		Westar	"	"	Oct. 1
	B. napus hybrid	Hybrid 1 (Regent x Karat)	"	"	Oct. 1
	TT *B. napus*	Line 1 (TT Hanna)	"	"	Oct. 4
		Line 2 (TT SV02231)	"	"	Oct. 4
		OAC Triton	"	"	Oct. 4
		OAC Triumph	"	"	Oct. 4
		Tribute	"	"	Oct. 4
		TT Regent		not used in this year	
	TT *B. napus* hybrid	Hybrid 2 (TT Regent x Karat)	"	"	Oct. 1
1986	*B. campestris*	Tobin	May 26	May 31	Aug. 29
	B. juncea	Cutlass	"	"	Sept. 9
		Domo	"	"	Sept. 9
	B. napus	Andor	"	"	Sept. 18
		Hanna	"	"	Sept. 18
		Karat	"	"	Sept. 18
		Regent	"	"	Sept. 15
		SV02231	"	"	Sept. 19
		Topas	"	"	Sept. 18
		Westar	"	"	Sept. 15
	B. napus hybrid	Hybrid 1 (Regent x Karat)	"	"	Sept. 18
	TT *B. napus*	Line 1 (TT Hanna)	"	"	Sept. 18
		Line 2 (TT SV02231)	"	"	Sept. 19
		OAC Triton	"	"	Sept. 19
		OAC Triumph	"	"	Sept. 19
		Tribute	"	"	Sept. 19
		TT Regent	"	"	Sept. 19
	TT *B. napus* hybrid	Hybrid 2 (TT Regent x Karat)	"	"	Sept. 18

† TT = triazine-tolerant.

At maturity, the canola plants were hand-cut approximately 5 cm above ground level and placed in large cotton bags. The samples were dried to constant weight before threshing in a stationary thresher.

A number of measurements were made on each plot. The time to 50 percent flowering was recorded for each entry in the experiment when an estimated 50 percent of the *Brassica* plants in the two centre rows of the whole plot had at least one flower open. Plant counts were made on the Brassicas twice during the experiment. The first count was made shortly after plant emergence, the second when the plants were harvested. Seed yield and 1000-seed weights were recorded. Harvest indices[2] were calculated. A five-plant subsample was used to estimate canola plant height 20 days after the date of 50% flowering.

Data analysis. Preliminary data analysis showed that while the year effect was significant for almost all parameters, the year x treatment interaction was not significant. Spearman's coefficient of rank correlation also showed no significant difference in ranking of the cultivars/lines between the two years used in the study. Therefore, once the data were checked for homoscedasticity, analysis of variance on data combined over years was conducted according to a mixed model where years and replications were treated as random effects and the weed and cultivar/line treatments were fixed effects (Gomez and Gomez, 1984 p. 328). Where the effect of the barley was not significant the data were combined. Single degree of freedom contrasts were used to compare the cultivar/line treatments that had been grouped as follows: *B. campestris, B. juncea, B. napus, B. napus* hybrid, triazine-tolerant *B. napus* and triazine-tolerant *B. napus* hybrid. Simple correlation coefficients were calculated among a number of yield parameters and *Brassica* seed yield in the presence and absence of barley. Stepwise linear multiple regression analysis was used to identify the most important parameters (plant count, stem weight and harvest index taken at final harvest and days to 50 percent flowering) contributing to *Brassica* seed yield under weedy and weed-free conditions.

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[2] Harvest index (%) = $\frac{\text{seed yield}}{\text{seed+stem weight}} \times 100$

RESULTS and DISCUSSION

Under weed-free conditions, the yield potential of the *Brassica* used in this experiment differed considerably (Table 3). The two *B. juncea* cultivars had the highest seed yield under weed-free conditions. They out-yielded two popular canola cultivars, Westar (*B. napus*) and Tobin (*B. campestris*) by 134 and 22%, respectively (Table 4). If the *B. juncea* yield potential shown in this experiment exists in recently announced canola-quality *B. juncea* lines (Love and Rakow, 1989), they will receive wide acceptance in moist, as well as drier, short-season canola producing areas.

The yield advantage of the hybrids grown under weed-free conditions was clearly demonstrated. Best parent heterosis for the Regent x Karat F_1 (Hybrid 1) was 56%. Heterosis for the triazine-tolerant *B. napus* hybrid (Hybrid 2) was 84% in 1986 (the only year in which both parents were grown). The hybrid *B. napus* out-performed the standard *B. napus* cultivars/lines, but the yield did not approach that obtained by *B. campestris* or *B. juncea* (Table 4).

No difference in yield was evident between Westar and the other *B. napus* cultivars/lines in the test (Table 4). On an individual cultivar basis however, two European cultivars, Hanna and Topas, yielded 17 and 19% more than Westar, respectively (Table 3).

All the triazine-tolerant B. napus cultivars/lines yielded less than the non-triazine-tolerant *B. napus* entries (Table 4). Yield was anywhere from 41 to 88% of that of Westar. One positive observation was the improved yielding ability of newer triazine-tolerant cultivars which indicated that advances can be made through careful parental selection. Triazine-tolerant Brassicas appear to have a legitimate role as an alternative crop choice where triazine herbicides are used in the rotation.

Under weed-free conditions, the *Brassica* groups can be ranked from the highest seed yield to the lowest, as follows: *B. juncea*>*B. campestris*>hybrid *B. napus*>*B. napus*=triazine-tolerant *B. napus* hybrid>triazine-tolerant *B. napus*.

Brassica seed yield was reduced by barley. Results from this experiment indicated that *Brassica* cultivars/lines that have high yield potential under weed-free conditions also have higher seed yields in the presence of barley. Over all entries in the experiment, barley reduced seed yield by 61% (Table 3).

The yield response of the *Brassica* cultivars/lines to competition varied. *Brassica juncea* and *B. campestris* seed yields were approximately 53% of the weed-free values. Because of the high yield potential of these cultivars, this represented a 1.6 and 1.3 tonne/ha loss for *B. juncea* and *B. campestris* due to barley.

Table 3. Mean *Brassica* seed yield and planting to flowering interval, with or without barley, combined over years.

Cultivar /line	Seed yield (g/m^2)			Planting to flowering (days)	
	Barley absent	Barley present	% of weed-free	Barley absent	Barley present
B. campestris					
Tobin	275	143	52	40	40
B. juncea					
Cutlass	337	179	53	40	40
Domo	333	176	53	41	42
B. napus					
Andor	126	42	33	48	49
Hanna	167	75	45	56	56
Karat	99	34	34	54	55
Regent	129	39	30	50	50
SV02231	133	35	26	52	53
Topas	171	47	27	51	52
Westar	143	47	33	49	49
Hybrid *B. napus*					
Hybrid 1	201	78	39	51	51
Triazine-tolerant *B. napus* hybrid					
Hybrid 2	150	33	22	51	51
Triazine-tolerant *B. napus*					
Line 1	100	37	37	53	53
Line 2	126	39	31	51	51
OAC Triton	58	23	40	52	52
OAC Triumph	112	28	25	50	50
Tribute	81	28	34	48	49
Regent[†]	47	32	68	49	49
SE	16.5		5.2	1.0	

[†] For reference, grown only in 1986.

Table 4. Mean seed yields of *Brassica* groups and single degree of freedom contrasts, with or without barley, combined over years.

Group[§]	Seed yield (g/m^2) Barley Absent	Seed yield (g/m^2) Barley Present	Contrast	Significance[†] Barley Absent	Significance[†] Barley Present
B. campestris	275	143	*B. campestris* vs *B. juncea*	**	**
B. juncea	335	177	*B. campestris* vs *B. napus*	**	**
B. napus	138	46	*B. campestris* vs *B. napus* hybrid	**	**
B. napus hybrid	201	78	*B. juncea* vs *B. napus*	**	**
TT *B. napus*	97	31	*B. napus* vs *B. napus* hybrid	**	*
TT *B. napus* hybrid	150	33	*B. napus* vs TT *B. napus*	**	ns
Westar	143	47	*B. napus* vs TT *B. napus* hybrid	ns	ns
Other *B. napus*	137	45	Westar vs other *B. napus*	ns	ns

[†] ns, not significant; *, significant at $P \leq 0.05$; **, significant at $P \leq 0.01$. Note not all comparisions are totally independent of each other.

[§] TT, triazine-tolerant.

Brassica napus material in the presence of barley yielded approximately 33% of the weed-free yield (Table 3). Since the *B. napus* was lower yielding under weed-free conditions, this resulted in a 0.9 tonne/ha reduction in seed yield attributable to the weed presence. A high weed-free yield did not always translate into a higher yield under weedy conditions. The cultivar Topas had the highest weed-free yield but did not yield significantly more than lower yielding varieties under weedy conditions.

As measured by seed yield, hybridization did not result in plants that were more competitive with barley than conventional *B. napus*. Hybrid 1 had a high seed yield under weed-free conditions but only maintained 39% of this yield when barley was present. This was only slightly more than the 33% of weed-free yield observed in the *B. napus* cultivars/lines and much less (14%) than weedy *B. campestris* and *B. juncea* yields.

Heterosis shown for seed yield in triazine-tolerant Regent x Karat (Hybrid 2) under weed-free conditions did not translate into a greater ability to compete with barley either. The triazine-tolerant hybrid attained only 22% of its weed-free yield which was less than all the other *B. napus* material.

Within the *B. napus* and triazine-tolerant *B. napus* groups, some cultivars/lines were superior at maintaining yield under weedy conditions. For instance, Hanna and Topas had similar weed-free yields but yielded 45 and 27% of their respective weed-free values when barley was present. OAC Triton had the lowest weed-free yield of the triazine-tolerant *B. napus* cultivars/lines but maintained the highest percentage of yield (40%) under weedy conditions. This indicates that if producers accept the concept of threshold levels of weeds, rather than weed-free production systems, crop cultivars should be selected under similar conditions.

Based on *Brassica* seed production under Lacombe conditions, the groups ranked as follows, in terms of yield maintenance in the presence of barley,: *B. juncea*>*B. campestris*>hybrid *B. napus*>*B. napus*=triazine-tolerant *B. napus*=triazine-tolerant *B. napus* hybrid.

Correlation of seed yield and yield parameters identified several characteristics that were critical to *Brassica* seed yield both in the presence and absence of barley at Lacombe (Table 5). These were: early flowering, high dry matter production and a greater amount of dry matter partitioned into seed (harvest index). When barley was present, maintenance of plant stand was also important in determining final seed yield.

Time to flowering and subsequent pod development can affect seed yield. This is especially true if the Brassicas have similar seed filling rates and are grown in short-season areas where the time available to fill seed is limited. The time to 50% flower of the *Brassica* cultivars/lines ranged from 40 days in Tobin to 56 days in Hanna (Table 3).

Table 5. Correlation coefficients between *Brassica* final harvest parameters, with or without barley, combined over years.

		Parameters†					
	Barley	Seed yield (g/m^2)	Harvest count (#/m^2)	Planting to flowering (days)	Stem weight (g/m^2)	Harvest index (%)	1000-seed weight (g)
Seed yield	Absent	1.00	-0.03	-0.70**	0.43**	0.82**	0.29**
	Present	1.00	0.24**	-0.73**	0.57**	0.91**	-0.01

† **, significant at P≤0.01.

Although there was a significant difference (not shown) in the interval from planting to 50% flowering of the Brassicas in the presence or absence of barley, the overall mean increase of 0.4 day under weedy conditions was not large. It is unlikely that this small delay in time to flower would shorten the available filling period.

The time between planting and flowering of the *B. campestris*, *B. juncea* and *B. napus* entries in this experiment was longer than that observed in many canola-producing areas because of the low average temperatures at Lacombe (Thomas, 1988 pers. comm.). It was longer than that recorded by Sernyk and Stefansson (1983) in Manitoba and more like the times Grant and Beversdorf (1985a) recorded for similar lines grown in Ontario.

The high yielding *B. juncea* and *B. campestris* cultivars also had the shortest time to 50% flower. Rapid pod development, combined with the determinate nature of this material, provided ample time to fill seed prior to frost. The best adapted *B. napus* cultivar, Westar, required 49 days to flower, but did not have the highest yield of the *B. napus* entries under weed-free conditions. This suggests that some of the later flowering cultivars/lines filled their pods faster than Westar. The yield of the *B. napus* material in this experiment appeared to be limited by both time to 50% flower and the time from 50% flower to first frost. As the *Brassica* cultivar/line had more effect on the planting to flowering interval than the presence of barley, it is imperative that producers select Brassicas that are recommended for their growing areas.

Brassicas growing at Lacombe have the potential to produce large amounts of dry matter (shoot material) (Table 6). Weed-free Regent, Karat and Hybrid 1 (Regent x Karat) produced twice the amount of dry matter (area basis) reported by Sernyk and Stefansson (1983) for the same material grown in Winnipeg under weed-free conditions. The dry matter production ranged from 13.9 tonnes/ha for the Hybrid 1 down to an average 8.8 tonnes/ha for the triazine-tolerant *B. napus* cultivars/lines.

In the short-season environment at Lacombe, high dry matter production did not always translate into high seed yield. Hybrid 1 (Regent x Karat), while ranking first for dry matter production, ranked third for seed yield when barley was absent. Because *Brassica* seed yield is dependent on events that are sequential, the ability to produce a dry matter base for future flowering and pod development is critical to seed yield. The amount of stem material remaining at harvest reflects the dry matter resource that is available at pod set. In general, the cultivars/lines that produced the most stem material were also late-flowering (Tables 3 and 6).

It has been suggested that tall, large plants may be more competitive under weedy conditions (Staniforth, 1961; Kawano *et al.* 1974). This premise did not hold true for the Brassicas grown at Lacombe. *Brassica* plant height was unaffected by the presence of

Table 6. Mean *Brassica* shoot weight and stem weight, with or without barley, combined over years.

Cultivar /line	Shoot weight (g/m^2)		Stem weight (g/m^2)		
	Barley absent	Barley present	Barley absent	Barley present	% of weed-free
B. campestris					
Tobin	1159	594	883	452	51
B. juncea					
Cutlass	1271	700	934	521	56
Domo	1400	760	1067	584	55
B. napus					
Andor	1034	456	908	413	45
Hanna	1160	662	993	587	59
Karat	1314	536	1216	502	41
Regent	1226	499	1096	460	42
SV02231	1226	468	1092	433	40
Topas	1303	570	1132	522	46
Westar	1219	571	1075	524	49
Hybrid *B. napus*					
Hybrid 1	1385	683	1183	605	51
Triazine-tolerant *B. napus* hybrid					
Hybrid 2	1070	360	920	327	36
Triazine-tolerant *B. napus*					
Line 1	851	466	750	430	57
Line 2	1090	403	964	364	38
OAC Triton	793	328	735	306	42
OAC Triumph	994	411	882	383	43
Tribute	631	273	552	245	44
Regent[†]	976	326	907	477	53
SE	96		84		3.7

[†] For reference, grown only in 1986.

barley. Plants with high stem weights were not necessarily tall (Table 7) and tall plants were not necessarily high yielding. Tobin, one of the highest yielding Brassicas, had a relatively low stem weight and was one of the shortest entries in the experiment. The maintenance of dry matter in the presence of weeds appeared to be essential to high seed yield. *B. juncea* and *B. campestris* were high yielding and maintained over 50% of their weed-free stem weights when grown with barley. While these plants were the same height as their weed-free counter-parts, they had thinner stems.

Obviously, post-flowering factors come into play in the development of seed yield for some of the entries. For instance, Hanna, which maintained 59% of its weed-free stem weight when barley was present, produced only 45% of the weed-free seed yield (Tables 3 and 6). This suggests that Hanna had the potential (based on stem size) to be higher yielding. No doubt the length of the growing season was a serious limitation.

The partitioning of dry matter into seed (harvest index) was an important post-flowering factor contributing to seed yield. Harvest index was highly correlated with seed yield (Table 5). The high yielding *B. juncea* and *B. campestris* groups had harvest indices over 24% (Table 7). The low harvest indices of the *B. napus* groups (10 to 13%) likely reflect environmental limitations at Lacombe. The late flowering, later maturing cultivars/lines had much less time to partition dry matter into pods and seeds than earlier maturing material. It was apparent that most lacked the high rates of filling needed to compensate for the short period from flowering to frost.

Harvest index was not affected by the presence of barley. Under weedy conditions, *Brassica* seed yield is therefore dependent on the total amount of dry matter present, as the same proportion will be partitioned into seed. This was exemplified by the difference in yield of the two most commonly grown cultivars in western Canada, Tobin (*B. campestris*) and Westar (*B. napus*) (Table 8). When barley was present, Tobin and Westar produced similar amounts of shoot material (594 and 571 g/m^2, Table 6). Because Tobin had a harvest index of 24.2% it yielded 143 g/m^2 while Westar, with a harvest index of 10.1%, yielded 47 g/m^2. There were also differences in harvest indices within *B. napus* and triazine-tolerant *B. napus* groups (Table 7). Cultivar choice for weedy situations, based on harvest index, has potential. This is supported by the fact that most of the variability in seed yield could be explained by harvest index (Table 9).

Individual seed weight was another factor that was not highly associated with final seed yield. In fact, 1000-seed weight was not correlated with seed yield when barley was present. Without exception, the 1000-seed weights of the Brassicas grown with barley were higher than those obtained when the Brassicas were grown under weed-free conditions (Table 10).

Table 7. Mean *Brassica* plant heights and harvest indices, combined over years.

Cultivar /line	Plant height[§] (cm)	Harvest index (%)
B. campestris		
Tobin	96	24.2
B. juncea		
Cutlass	107	26.2
Domo	110	23.6
B. napus		
Andor	105	10.3
Hanna	123	12.6
Karat	110	7.1
Regent	107	9.2
SV02231	108	9.2
Topas	102	10.4
Westar	107	10.1
Hybrid *B. napus*		
Hybrid 1	109	12.5
Triazine-tolerant *B. napus* hybrid		
Hybrid 2	97	11.0
Triazine-tolerant *B. napus*		
Line 1	114	9.8
Line 2	96	10.3
OAC Triton	102	6.9
OAC Triumph	98	9.2
Tribute	95	11.1
Regent[†]	121	8.7
SE	2.0	0.9

[†] For reference, grown only in 1986.

[§] Measured 20 days after 50% flowering.

Table 8. Mean harvest indices of *Brassica* groups and single degree of freedom contrasts, combined over barley treatments and years.

Group[†]	Harvest index (%)	Contrast	Significance[§]
B. campestris	24.3	*B. campestris* vs *B. juncea*	ns
B. juncea	24.9	*B. campestris* vs *B. napus*	**
B. napus	9.8	*B. campestris* vs *B. napus* hybrid	**
B. napus hybrid	12.5	*B. juncea* vs *B. napus*	**
TT *B. napus*	9.5	*B. napus* vs *B. napus* hybrid	**
TT *B. napus* hybrid	11.0	*B. napus* vs TT *B. napus*	ns
Westar	10.1	*B. napus* vs TT *B. napus* hybrid	ns
Other *B. napus*	9.8	Westar vs other *B. napus*	ns

[†] TT, triazine-tolerant.

[§] ns, not significant; *, significant at P≤0.05; **, significant at P≤0.01. Note not all comparisions are totally independent of each other.

Table 9. Standardized partial regression coefficients[†] for *Brassica* harvest index and shoot dry weight regressed on seed yield, with or without barley, combined over years and cultivars/lines.

Treatment	Harvest index (%)	Stem weight (g/m^2)	50% flower (days)	Harvest count (#/m^2)	1000-seed weight (g)	R^2	SE[§]
Barley absent	0.65					0.67	55.99
	0.69	0.07				0.93	25.98
	0.80[§]	0.48	-0.11			0.94	24.83
Barley present	0.93					0.83	23.47
	0.84	0.33				0.93	14.98
	0.83	0.36			0.08	0.94	14.33
	0.76	0.36	-0.09		0.07	0.94	14.06
	0.75	0.39	-0.09	-0.06	0.06	0.95	13.81

[†] Derived from the following equations: *Brassica* seed yield (g/m^2), barley absent = -40.83 - 2.08 x 50% flower + 0.14 x stem weight + 12.03 x harvest index; *Brassica* seed yield (g/m^2), barley present = -41.79 - 1.05 x 50% flower - 0.14 x harvest count + 0.16 x stem weight + 10.61 x 1000-seed weight + 5.83 x harvest index.

[§] Square root of the regression error mean square.

Table 10. Mean *Brassica* 1000-seed weights, with or without barley, combined over years.

Cultivar /line	1000-seed weight (g)	
	Barley absent	Barley present
B. campestris		
Tobin	2.84	2.93
B. juncea		
Cutlass	2.86	2.99
Domo	2.97	3.06
B. napus		
Andor	2.70	3.14
Hanna	2.47	2.76
Karat	2.27	2.49
Regent	2.61	2.89
SV02231	2.40	2.83
Topas	2.46	2.96
Westar	3.23	3.50
Hybrid *B. napus*		
Hybrid 1	2.53	2.78
Triazine-tolerant *B. napus* hybrid		
Hybrid 2	2.46	3.01
Triazine-tolerant *B. napus*		
Line 1	2.42	2.78
Line 2	2.40	2.76
OAC Triton	2.78	3.11
OAC Triumph	2.57	2.76
Tribute	2.71	3.44
Regent†	2.72	3.03
SE	0.94	

† For reference, grown only in 1986.

Charcteristics which distinguish the different Brassicas were not particularly evident. *B. campestris* and *B. juncea* generally have many more seeds that are smaller than those of *B. napus*. These two groups actually had larger seeds than all the *B. napus* entries except Westar under weed-free conditions (Table 11). This could be interpreted to mean that there was a source limitation in these cultivars/lines. However, it is also likely that seed filling was curtailed by frost.

Seed yield may be affected by plant stand. While no differences in emergence or harvest counts in the *Brassica* cultivars/lines used in this experiment were observed, there were slightly fewer plants in the weedy plots at emergence (Table 12). The association between plant stand and seed yield when barley was present can be attributed to initial stand and to a much larger plant loss over the season in the weedy plots. The retention of plant stand may be an indicator of superior *Brassica* competitive ability. The two *B. juncea* cultivars had the lowest plant mortality when barley was present (6.7%), of the entries in the experiment, and the highest seed yields (Table 13). However, the enormous potential for yield compensation in the Brassicas was also evident. Tobin which had a high mortality rate (20.7%) produced more seed than other entries with similar plant loss over the season.

Table 11. Mean 1000-seed weights of *Brassica* groups and single degree of freedom contrasts, with or without barley, combined over years.

	1000-seed weight (g)			Significance†	
Group§	Barley		Contrast	Barley	
	Absent	Present		Absent	Present
B. campestris	2.84	2.93	*B. campestris* vs *B. juncea*	ns	ns
B. juncea	2.92	3.03	*B. campestris* vs *B. napus*	**	ns
B. napus	2.59	2.93	*B. campestris* vs *B. napus* hybrid	**	ns
B. napus hybrid	2.53	2.78	*B. juncea* vs *B. napus*	**	ns
TT *B. napus*	2.57	2.97	*B. napus* vs *B. napus* hybrid	ns	*
TT *B. napus* hybrid	2.46	3.01	*B. napus* vs TT *B. napus*	ns	ns
Westar	3.23	3.50	*B. napus* vs TT *B. napus* hybrid	ns	ns
Other *B. napus*	2.48	2.85	Westar vs other *B. napus*	ns	**

† ns, not significant; *, significant at $P \leq 0.05$; **, significant at $P \leq 0.01$. Note not all comparisions are totally independent of each other.

§ TT, triazine-tolerant.

Table 12. Mean *Brassica* emergence plant counts, harvest counts and percent survival, grouped over cultivars and years.

Barley	Emergence count (#/m^2)	Harvest count (#/m^2)	Survival (%)
Absent	97	92	96
Present	83	71	88
SE	2.6	2.7	2.1

Table 13. Mean percent plant mortality of *Brassica* groups and single degree of freedom contrasts, with or without barley, combined over years.

Group[§]	Mortality (%)		Contrast	Significance[†]	
	Barley			Barley	
	Absent	Present		Absent	Present
B. campestris	6.2	20.7	*B. campestris* vs *B. juncea*	ns	**
B. juncea	11.1	6.7	*B. campestris* vs *B. napus*	ns	ns
B. napus	10.4	12.1	*B. campestris* vs *B. napus* hybrid	ns	ns
B. napus hybrid	13.1	12.2	*B. juncea* vs *B. napus*	ns	*
TT *B. napus*	10.8	16.2	*B. napus* vs *B. napus* hybrid	ns	ns
TT *B. napus* hybrid	6.5	20.3	*B. napus* vs TT *B. napus*	ns	ns
Westar	7.2	20.4	*B. napus* vs TT *B. napus* hybrid	ns	ns
Other *B. napus*	10.8	13.5	Westar vs other *B. napus*	ns	ns

[†] ns, not significant; *, significant at $P \leq 0.05$; **, significant at $P \leq 0.01$. Note not all comparisions are totally independent of each other.

[§] TT, triazine-tolerant.

SUMMARY

The difference in ability to maintain yield under weedy conditions among the cultivars/lines included in this experiment was clearly demonstrated. Barley reduced seed yield of all the *Brassica* cultivars/lines. The greatest loss in seed yield occurred in the triazine-tolerant material, the least in *B. juncea* and *B. campestris*. The traits which made *B. juncea* and *B. campestris* successful competitors were no doubt influenced by the short-season environment at Lacombe. Results from other research have suggested that tall plants that produce a lot of vegetative material compete most successfully with weeds, but the highest yielding plants in this experiment did not fit this description. *Brassica* plants with the highest yield under weedy conditions flowered early. This assured ample time to set and fill pods before frost. The plants were of medium stature and did not produce the most vegetative material. More importantly, they were able to maintain dry matter production when barley was present and were able to use this dry matter as a base for future seed yield. Since barley did not alter the proportion of dry matter that went into the seed, the overall dry matter mass was critical.

The fact that some cultivars/lines responded differently under weed-free and weedy conditions indicated that variety selection may be important if producers expect some weeds in their fields. As information about how varieties perform in weedy situations is largely unavailable, selection of the best adapted varieties is the only guideline that can be used at this time.

CHAPTER 2

COMPETITION BETWEEN BARLEY AND CANOLA GROWN AT A RANGE OF POPULATION DENSITIES: EFFECTS ON THE CANOLA CROP

INTRODUCTION

During early stages of plant development the relationship between plant density per unit area and weight (dry matter, yield) is linear (Harper, 1977, p. 152). Over time, there is a departure from this linear relationship, and weight (yield) per unit area becomes independent of seeding rate (Harper, 1977 p. 154). The relationship between plant density and dry matter can be altered by stress. Stress was defined by Grime (1977) as the external constraints that limit the rate of dry matter production in all or part of the vegetation. In situations were plants are grown at high densities, stress is imposed by the plant's competition for finite resources needed for growth. Plants respond to the stress imposed by density in one or both of two ways. They may exhibit plastic responses by varying the amount of growth in various organs or there may be mortality of whole plants or plant parts.

Agronomists have concentrated on the relationship between units of economic return and plant density. When yield per unit area is measured as reproductive or seed yield the association with density usually has been parabolic. When yield is measured as total vegetative material, the yield-density relationship is frequently a curve asymptotically approaching a ceiling level (Holliday, 1960a; Holliday, 1960b).

Mathematical models have been developed for both predictive (*i.e.*, optimum plant densities) and interpretive purposes. In general, equations that have been used relate mean yield per plant rather than yield per unit area to plant density. The relationship between the reciprocal of mean yield per plant and plant density, giving rise to a series of 'reciprocal equations', has best described the impact of density on yield (Willey and Heath, 1969).

A plant can be viewed as a population of parts. Changes in the number of individual units (*i.e.* flower weight, seed weight) mean that the size of the whole plant will vary. The numbers of each unit are modified by plant age and by environment (Harper, 1977 p.195). Stress imposed at any time during plant development may alter the number of individual units and, ultimately, yield. Plasticity of organ development in individual plants assures seed production when plants are grown under adverse conditions and, in crop plants in particular, contributes to yield stability (Bradshaw, 1965). Seed yield can be explained by changes that occur in plant components that contribute to yield.

Unlike the yield-density responses for small-grained cereals (Guitard *et al.*, 1961; Larter *et al.*, 1971), the yield responses of pure stands of *B. napus* and *B. campestris* varieties grown in western Canada have been variable. Some researchers have been able to identify seeding rates that maximize yields of some varieties (Kondra, 1975; Kondra, 1977; Brandt, 1985; Morrison *et al.* 1990) while others found no yield differences in *B. napus* or *B. campestris* over a range of seeding rates (Christensen and Drabble, 1984; Degenhardt and Kondra 1981a; Mahasi, 1986). Clarke *et al.* (1978) observed that each increase in seeding rate resulted in significant yield increases in both drilled and broadcast *B. napus*. These experiments were all conducted under weed-free conditions and none of the researchers applied reciprocal equations in order to identify optimum plant densities or to help explain the yield responses they recorded.

The effect of seeding rate on the components of seed yield for monocropped canola has also been variable. Although Degenhardt and Kondra (1981a) did not find that seeding rate affected seed yield or vegetative yield of *B. napus* grown in the Edmonton area, seeding rate did affect dry matter partitioning as harvest index was lower at the highest seeding rate. Seed yield per plant and the number of branches per plant declined as seed rate increased while 1000-seed weights remained unchanged. In experiments where *B. napus* seed yield increased with increments in plant density, Clarke *et al.* (1978) and Clarke and Simpson (1978b) found that the numbers of branches and pods per plant were reduced as crop density increased. Clarke *et al.* (1978), from their seeding method-rate experiment reported that *B. napus* seeds per pod and 1000 seed weights were unaffected by increased crop density while Clarke and Simpson (1978b) found that seeds per pod declined and 1000-seed weight increased with *B. napus* plant density in an irrigation-rate experiment.

Fewer researchers have examined the effect of plant density on both *B. napus* and *B. campestris* in the same experiment. McGregor (1987) included both species in an experiment in which he examined plant recovery from hail injury. He reported results similar to those of Clarke and Simpson (1978b) for *B. napus* but found that plant density had little effect on *B. campestris* seeds per pod while the 1000-seed weights were variable.

Crop competition is recognized as an integral part of any weed control strategy. Higher than normal wheat seeding rates in weedy Saskatchewan fields increased yield by 16% (Godel 1935). Since that time, very few agronomists have examined the effect of competition between weeds and crop plants grown at a range of plant densities, and even fewer have looked at non-cereal crops.

Lawson (1982) reported that weeds interfered with the vegetative development of peas primarily by reducing branching at low crop densities. At higher crop densities, the effect of the weeds was reduced as inter-plant competition became a more important factor during vegetative growth. Weeds reduced total pea yield and the number of pods by a constant amount across the range of pea densities tested. The pea plants had fewer pods per plant and more unfilled pods when grown under weedy conditions while the number of peas per pod and individual pea weights were not affected.

Spitters (1983a, 1983b) used Willey and Heath's (1969) density-response equations as a basis to explore intra-specific competition in a mono-crop, inter-specific competition between crop mixtures, and niche differentiation between species. Based on biomass production, Spitters (1983a) showed that intra-specific competition in mono-cropped corn was much greater than inter-specific competition between a corn-peanut (*Arachis hypogaea* L.) mixture. One corn plant added to a corn-peanut mixture had the effect of 6.9 peanut plants on the corn. For a peanut plant, one corn plant was equivalent to only 1.6 other peanut plants. In the case of this mixture, intra-specific competition was greater than inter-specific competition. The biomass production of the corn and peanut plants was only partially limited by overlapping niches.

The Parkland region of the prairies has a unique weed situation due to the barley-canola rotation used in this area. Barley emerging the year after harvest creates a weed situation that is expensive to control. If producers could limit yield loss by seeding at heavier rates, they might be able to reduce their weed control input costs. The primary objective of this experiment was to identify optimum seeding rates for both *B. campestris* and *B. napus* under weedy and weed-free conditions. The second objective was to explain the observed yield responses by examining individual yield components.

MATERIALS and METHODS

Field procedure. Field experiments were conducted at the Agriculture Canada Research Station, Lacombe, Alberta (52° 28' latitude, 113° 44' longitude) in 1985 and 1986. The plots were established on a weed-free, fallowed Ponoka clay loam soil (sand 26%, silt 34%, clay 40%, OM 8%, pH 6.0). The seedbed was prepared by cultivating two or three times in the spring with a vibrashank cultivator, followed by harrowing with a spike-tooth harrow.

Brassica campestris cv Tobin and *B. napus* cv Westar canola were seeded as the crop and *Hordeum vulgare* cv Galt was used to simulate volunteer barley. The experiment was set out in a split-block design. Individual plots were 2.7 by 2.7 m. Tobin and Westar canola seeded at target densities of 25, 50, 100, 150, 200 and 250 plants/m^2 arranged in a randomized complete-block design constituted the main effects or whole plots of this experiment. The sub-plot weed treatments, barley seeded at 75 plants/m^2 and no barley, were randomized in strips across each of the four replications. Percent germination and estimated seed vigour were factored into the seeding rate calculations in each year. The crop and the weed were planted with a double disk press-type drill to emerge simultaneously. The crop and weed were seeded at right angles to each other in rows spaced 23 cm apart. The canola rows ran in an east-west direction while the barley rows ran north to south. DECIS 5 EC™[1] (deltamethrin) was applied post-emergence (6.2 a.i. g/ha) for flea beetle (*Phyllotreta cruciferae* Goeze, *P. striolata* Fab.) control.

After plant emergence, a 0.84-m^2 area was selected and marked in each plot. The following data were recorded in each quadrat: crop and weed plant counts at emergence and harvest, number of spike-bearing barley tillers at harvest, shoot dry weight of canola and barley at harvest, canola and barley seed yields, 1000-seed weights for canola and 250-seed weights for the barley. Harvest indices[2] were calculated. The seeding, emergence and harvest dates are listed in Table 1.

At maturity, canola and barley plants were hand-cut approximately 5 cm above ground level and placed in large cotton bags. The samples were dried to constant weights before threshing in a stationary thresher.

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[1] Uniroyal Chemical Ltd., 4-2216-27 Ave., N.E. Calgary, Alberta T2E 7A7

[2] Harvest index = $\frac{\text{seed yield}}{\text{seed+stem weight}} \times 100$

Table 1. Dates of seeding, emergence and harvest.

Year	Canola or barley	Seeding date	Emergence date	Harvest date
1985	Tobin	May 21	May 29	Aug. 28
	Barley in Tobin	May 22	May 29	Aug. 28
	Westar	May 21	May 29	Sept. 18
	Barley in Westar	May 22	May 29	Sept. 18
1986	Tobin	May 23	May 29	Sept. 5
	Barley in Tobin	May 23	May 29	Sept. 5
	Westar	May 23	May 29	Sept. 18
	Barley in Westar	May 23	May 29	Sept. 18

At harvest time, five-plant subsamples of canola and barley were selected at random from plants adjacent to the quadrat and harvested with the root attached. Plant heights and pod-bearing branch counts (primary, secondary, tertiary and quarternary) in the case of the canola plants, and tiller counts for the barley plants were made on the plants before they were individually wrapped in newspaper. The five plants were then put in a paper bag inside a large cotton sack to dry in an oven at 55 C. The roots of each plant in the canola subsample were separated from the shoot. The shoot was weighed before the pods were removed and counted. For a pod to be included in the pod count it had to have at least one developed seed. The pods containing seeds were weighed before the seed was harvested by hand threshing. The individual seeds were counted using an electronic seed counter[1] and then weighed. The total number of branches, seeds per pod and 1000-seed weights for the individual plants were calculated from the preceding information. The roots of each barley plant were removed and the plant shoot was weighed. The mature spikes were counted and removed. The number of spikelets on each spike was recorded before the spikes were hand-threshed. The seeds were counted and weighed. This information was used to calculate spikelets per spike, seeds per spikelet and 250-seed weight for each plant.

Data analysis. The effect of canola plant density and the presence of barley on canola plant mortality was examined using simple linear regression. Plant harvest count was regressed on canola emergence count. Comparisons between regression coefficients were made by the procedure outlined in Gomez and Gomez (1984, p. 373).

The relationship between canola plant density and plant shoot weight and seed yield was examined using the following two reciprocal models (Håkansson, 1983):

Model 1 $$\frac{X}{Y} = a + bX$$

Model 2 $$\frac{X}{Y} = a + bX + cX^2$$

where X=canola density at emergence (#/m^2) and Y=canola shoot weight or seed yield (g/m^2).

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[1] Electronic seed counter, Model 850-2, The Old Mill Company, Savage Industrial Center, Savage, Maryland, USA 20763

The effect of crop density on harvest index was examined using simple linear regression. Slopes of the lines were compared by the procedure previously mentioned.

Linear correlation was used to measure the association between canola seed yield on an area basis and canola seed yield on a per plant basis at harvest time. This was done so that inferences with respect to yield on an area basis could be drawn from individual plant parameters such as branch count, pod number *etc*. A log $_{10}$ and $\log_{10}+1$ transformation of pod number per plant and seed weight per plant, respectively was required to assure the data fit a normal distribution.

Regression was used to determine the relationship between canola density at emergence and the components of canola yield (branches, pods, seeds per pod and 1000-seed weight). The data (mean of the five-plant subsamples) were fitted with a linear, quadratic or cubic equation.

Stepwise linear multiple regression was used to identify the most important parameters contributing to canola seed yield (per plant basis) in the presence and absence of barley.

Biomass (total weight) was used as a measure of plant competition. Intra-specific competition between canola plants growing in a pure stand was assessed on an average weight per plant basis (Spitters1983a):

$$\text{Model 3} \qquad \frac{1}{\mathrm{Y}} = a + b\,\mathrm{X}$$

where Y=total weight per plant at harvest (g) and X=canola density at emergence (#/m^2). The ratio of a/b is used as a measure of intra-specific competitive stress. Inter-specific competition between canola and barley was examined using the multiple linear regression form:

$$\text{Model 4} \qquad \frac{1}{\mathrm{Y}} = a + b\,\mathrm{X} + c\,\mathrm{Z}$$

where Y=total weight per plant at harvest of either canola or barley, X=canola density at emergence (#/m^2) and Z=barley density at emergence (#/m^2). The ratios of b/c for canola and barley biomass are used to explain the relative competitive ability of each species. Inference about niche differentiation can be made from the relationship between the ratios. Weighted regression analysis was not used on Models 3 and 4 as variance did not increase as plant density increased.

RESULTS and DISCUSSION

Plants respond to the stress that increasing plant density imposes by altering the size or number of plant components or by increased plant mortality. The linear relationship between plant emergence count and harvest count indicated that no density-dependent mortality occurred in Tobin or Westar canola (Figure 1). The reduction in plant stand as density increased was not the same across years and canola cultivars, or when barley was present or absent. With the exception of Westar in 1986, crop stand mortality was 15% or less under weedy and weed-free conditions.

Crop plants such as soybeans and sunflowers appear to regulate population by increased plant death at plant populations well above 100 plant/m^2 (Harper, 1977 p. 175). Even the addition of barley plants in this experiment did not increase canola plant mortality. There was no indication of density-dependent mortality even when the combined barley-canola plant population was over 200 plants/m^2. High rates of plant mortality are unlikely to occur at plant densities normally used in cropping situations.

Further support of the premise that canola exhibits a plastic response to plant density came from fitting the shoot dry weight data with reciprocal equations (Figure 2). Under weed-free conditions shoot dry weight on an area basis remained relatively constant over the density ranged used. This meant that individual plants became progressively smaller as crop density increased.

This trend of smaller individual plants was also observed when barley was present. No matter at what density canola was seeded, the presence of barley resulted in lower canola shoot weight. At best, weedy canola shoot dry weight was half that produced by canola plants grown at the same density in pure stands. The overall rate of shoot biomass reduction per canola plant was greater when barley was present which could indicate that plant stand was more important under weedy conditions.

Individual slope comparisons in 1985 indicate that the change in shoot weight as plant density increased, in the presence of barley, was the same in both Westar and Tobin (Figure 2). In 1986, the shoot weight of individual Westar plants declined faster than in Tobin.

A major component of vegetative growth which was affected by plant density was total branches per plant. Total branch number declined as plant population

Figure 1. Relationship between canola emergence count and canola harvest count for Tobin and Westar, grown alone (open symbols, broken lines) and with barley (closed symbols, solid lines) in 1985 and 1986.

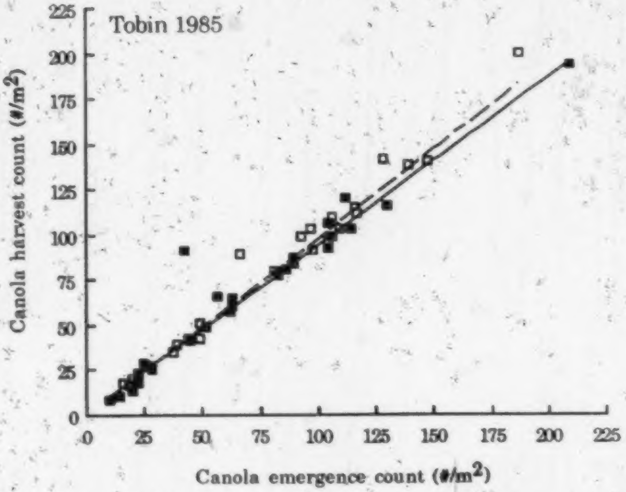
			Regression coefficients[†]			
Year	Cultivar	Barley	*a*	*b*	R^2	Significance[§]
1985	Tobin	Absent	-9.54×10^{-1}	9.85×10^{-1} (1.29×10^{-2})[Y]	0.99	**
		Present	2.62×10^{-1}	9.34×10^{-1} (1.56×10^{-2})	0.99	**
	Westar	Absent	1.07	8.94×10^{-1} (4.61×10^{-2})	0.94	**
		Present	6.33×10^{-1}	8.64×10^{-1} (3.08×10^{-2})	0.97	**
1986	Tobin	Absent	7.16×10^{-1}	8.86×10^{-1} (2.68×10^{-2})	0.98	**
		Present	-4.64×10^{-1}	8.50×10^{-1} (3.36×10^{-2})	0.97	**
	Westar	Absent	10.81	5.82×10^{-1} (5.16×10^{-2})	0.85	**
		Present	9.24×10^{-1}	7.82×10^{-1} (2.75×10^{-2})	0.97	**

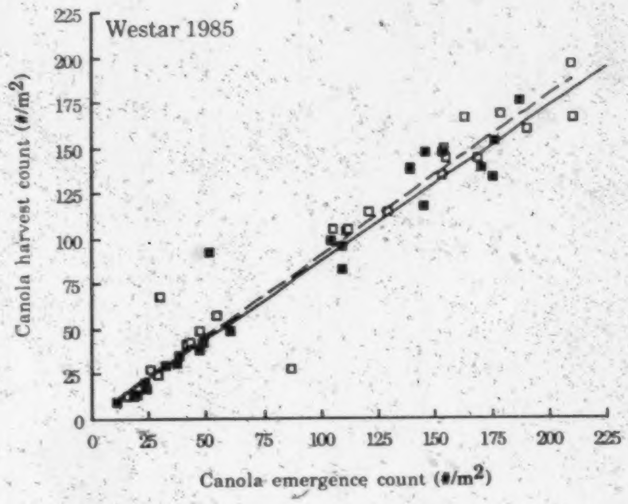
Slope (*b*) comparisons							Significance
Year	Cultivar	Barley		Year	Cultivar	Barley	
1985	Tobin	Absent	vs	1985	Tobin	Present	*
1986	Tobin	Absent	vs	1986	Tobin	Present	ns
1985	Tobin	Absent	vs	1986	Tobin	Absent	**
1985	Tobin	Present	vs	1986	Tobin	Present	*
1985	Westar	Absent	vs	1985	Westar	Present	ns
1986	Westar	Absent	vs	1986	Westar	Present	**
1985	Westar	Absent	vs	1986	Westar	Absent	**
1985	Westar	Present	vs	1986	Westar	Present	ns
1985	Tobin	Absent	vs	1985	Westar	Absent	ns
1985	Tobin	Present	vs	1985	Westar	Present	ns
1986	Tobin	Absent	vs	1986	Westar	Absent	**
1986	Tobin	Present	vs	1986	Westar	Present	ns

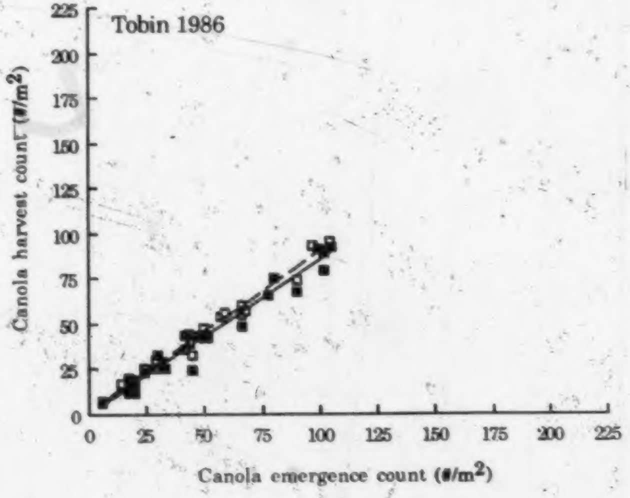
[†] Following the model, $Y=a+bX$ where Y is the harvest count ($\#/m^2$) and X is the emergence count ($\#/m^2$), n=24.

[§] ns, not significant; *, significant at $P\leq0.05$; **, significant at $P\leq0.01$.

[Y] Standard error bracketed.


Tobin 1985
Canola harvest count (#/m^2)
Canola emergence count (#/m^2)
0
25
50
75
100
125
150
175
200
225


Westar 1985
Canola harvest count (#/m^2)
Canola emergence count (#/m^2)
0
25
50
75
100
125
150
175
200
225


Tobin 1986
Canola harvest count (#/m^2)
Canola emergence count (#/m^2)
0
25
50
75
100
125
150
175
200
225

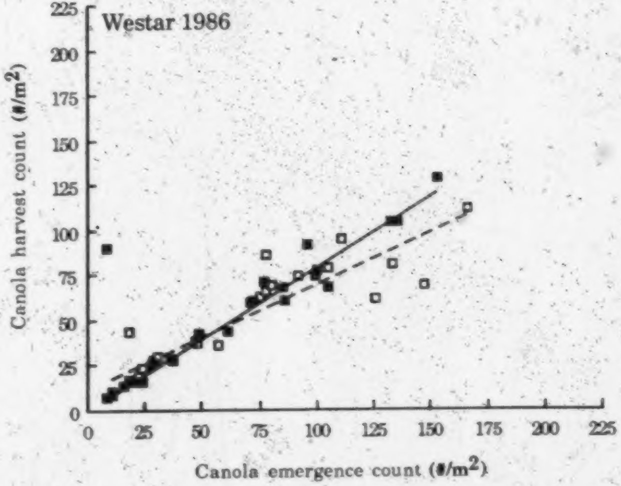

Westar 1986
Canola harvest count (#/m^2)
Canola emergence count (#/m^2)
0
25
50
75
100
125
150
175
200
225

Figure 2. Relationship between canola shoot weight and canola emergence count for Tobin and Westar, grown alone (open symbols, broken lines) and with barley (closed symbols, solid lines) in 1985 and 1986.

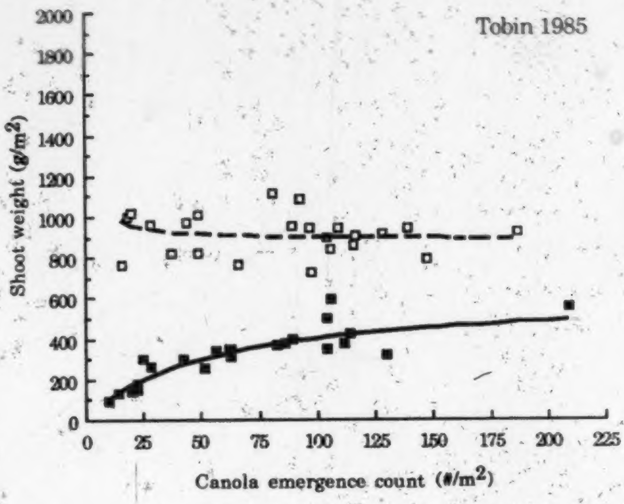
			Regression coefficients[†]			
Year	Cultivar	Barley	*a*	*b*	R^2	Significance[§]
1985	Tobin	Absent	-1.75×10^{-3}	1.13×10^{-3} (4.63×10^{-5})[Y]	0.96	**
		Present	8.74×10^{-2}	1.62×10^{-3} (1.57×10^{-4})	0.83	**
	Westar	Absent	-6.44×10^{-3}	9.90×10^{-4} (4.30×10^{-5})	0.96	**
		Present	6.38×10^{-2}	1.25×10^{-3} (1.06×10^{-4})	0.86	**
1986	Tobin	Absent	-5.00×10^{-4}	8.86×10^{-4} (7.04×10^{-5})	0.88	**
		Present	1.35×10^{-1}	1.03×10^{-3} (4.31×10^{-4})	0.21	*
	Westar	Absent	-4.40×10^{-3}	9.24×10^{-4} (6.53×10^{-5})	0.90	**
		Present	6.74×10^{-2}	1.49×10^{-3} (1.75×10^{-4})	0.77	**

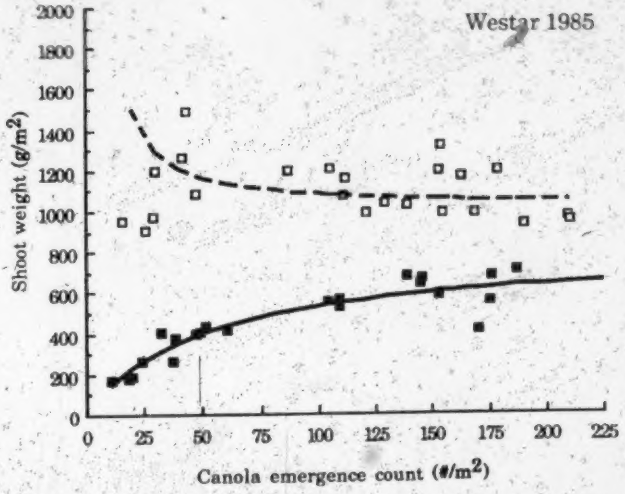
Slope (*b*) comparisons							Significance
Year	Cultivar	Barley		Year	Cultivar	Barley	
1985	Tobin	Absent	vs	1985	Tobin	Present	*
1986	Tobin	Absent	vs	1986	Tobin	Present	**
1985	Tobin	Absent	vs	1986	Tobin	Absent	ns
1985	Tobin	Present	vs	1986	Tobin	Present	**
1985	Westar	Absent	vs	1985	Westar	Present	**
1986	Westar	Absent	vs	1986	Westar	Present	*
1985	Westar	Absent	vs	1986	Westar	Absent	ns
1985	Westar	Present	vs	1986	Westar	Present	*
1985	Tobin	Absent	vs	1985	Westar	Absent	ns
1985	Tobin	Present	vs	1985	Westar	Present	ns
1986	Tobin	Absent	vs	1986	Westar	Absent	ns
1986	Tobin	Present	vs	1986	Westar	Present	**

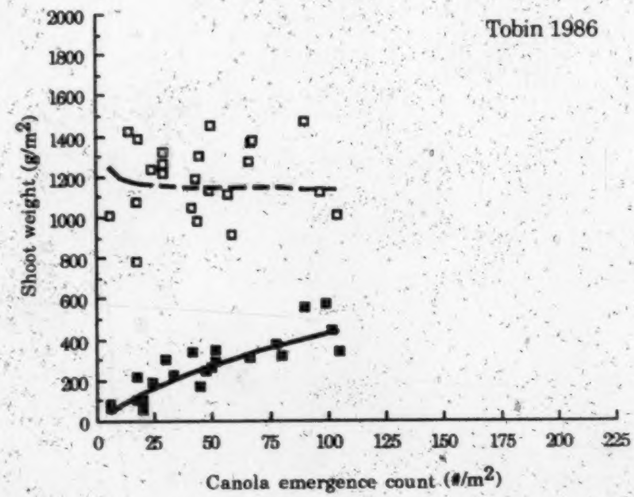
[†] Following the model, $X/Y=a+bX$ where Y is the shoot weight (g/m^2) and X is the emergence count ($\#/m^2$), n=24.

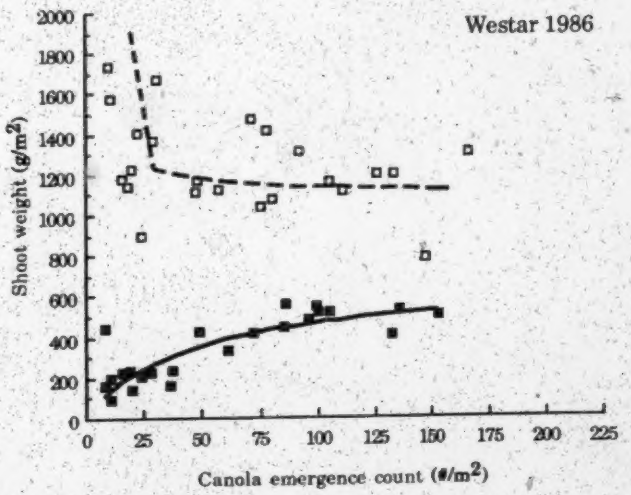
[§] ns, not significant; *, significant at $P\leq0.05$; **, significant at $P\leq0.01$.

[Y] Standard error bracketed.


Tobin 1985
Shoot weight (g/m^2)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
25
50
75
100
125
150
175
200
225
Canola emergence count (#/m^2)


Westar 1985
Shoot weight (g/m^2)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
25
50
75
100
125
150
175
200
225
Canola emergence count (#/m^2)


Tobin 1986
Shoot weight (g/m^2)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
25
50
75
100
125
150
175
200
225
Canola emergence count (#/m^2)


Westar 1986
Shoot weight (g/m^2)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
25
50
75
100
125
150
175
200
225
Canola emergence count (#/m^2)

increased (Figure 3). This trend was much more evident in 1986 than in 1985, when both cultivars had more branches in total. While the two canola cultivars had a similar number of primary branches when grown in pure stands, Tobin had many more secondary, tertiary and even quaternary branches (Table 2). This was characteristic of the differences expected between *B. napus* and *B. campestris* cultivars. The reduction in branching can be associated with the decline in shoot weight seen at high plant populations.

No relationship between total branches/plant and canola emergence count was observed when barley was present. The canola plants had approximately the same number of branches as weed-free canola grown at the highest plant densities. Branching was reduced to a minimum by the presence of the weed. Tobin averaged 6.7 ±0.4 branches in 1985 and 7.1 ±0.5 branches in 1986 while Westar had 4.2 ±0.3 and 6.2 ±0.6 branches in 1985 and 1986, respectively. Even under weedy conditions, Tobin had one to two more pod-bearing branches than Westar.

Although individual plants appeared to have the same number of branches at all the crop densities when barley was present, the size (weight) of the branches had to be smaller at high plant populations because of the reduction in shoot dry weight that was observed. The pod-filling potential of each branch was reduced as plant density increased because stem material is an important assimilate source for young seeds (Major *et al.*, 1984).

No optimum canola density for maximum seed yield was identified. When barley was absent, the highest canola yields were generally attained at the lowest plant densities (Figure 4). This was particularly true for Westar, where yield declined as plant population increased. Intra-specific competition between the weed-free Westar plants had a larger effect on seed yield than on total dry matter production. The demarcation between the curve and the horizontal asymptote, characteristic of the reciprocal equation used, was slight in Tobin. Under weed-free conditions, Tobin yield was similar across plant density. In this situation, as plant density increased, the mean contribution made to yield by each member of the population declined.

The yield of the two cultivars differed in the two experiment-years. Westar out-yielded Tobin at the low seeding rates in 1985, but in 1986, Tobin yielded higher than Westar grown at any density. This difference in seed yield occurred even though the two cultivars produced a similar amount of shoot material in 1986 (Figure 2). The dry

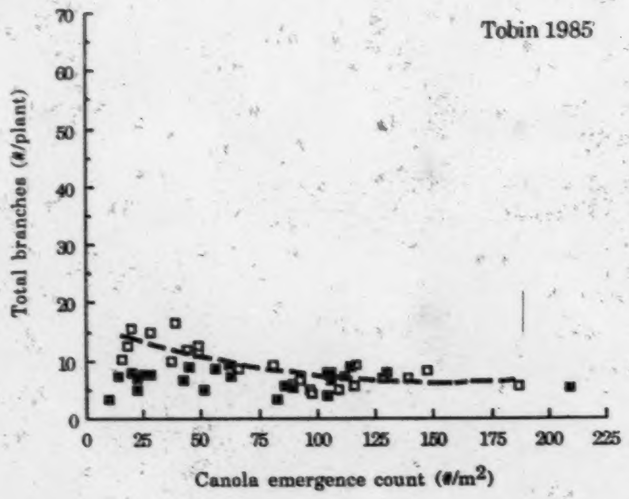
Figure 3. Relationship between total branch number and canola emergence count for Tobin and Westar, grown alone (open symbols, broken lines) and with barley (closed symbols, solid lines) in 1985 and 1986.

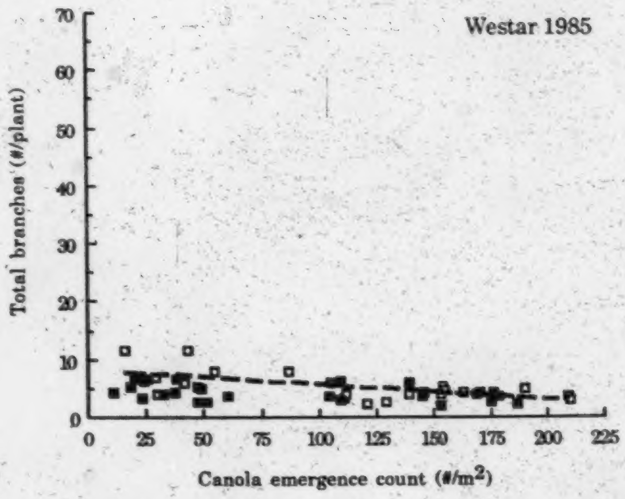
			Regression coefficients[†]					
Year	Cultivar	Barley	*a*	*b*	*c*	d	R^2	Significance[§]
1985	Tobin	Absent	16.28	-1.34×10^{-1}	4.40×10^{-4}		0.65	**
				(3.53×10^{-2})[Y]	(1.93×10^{-4})			
		Present	no relationship					
	Westar	Absent	8.10	-2.52×10^{-2}			0.41	**
				(6.42×10^{-3})				
		Present	no relationship					
1986	Tobin	Absent	81.73	-3.16	5.02×10^{-2}	-2.56×10^{-4}	0.84	**
				(5.62×10^{-1})	(1.18×10^{-2})	(7.06×10^{-5})		
		Present	no relationship					
	Westar	Absent	21.79	-1.13×10^{-1}			0.32	**
				(3.58×10^{-2})				
		Present	no relationship					

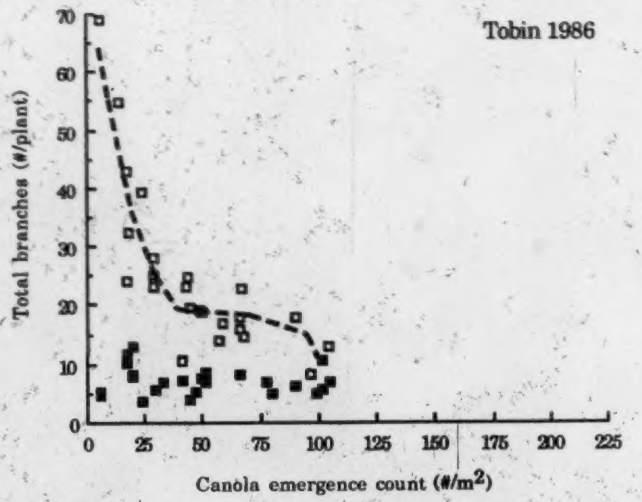
[†] Following the model, Y=*a* + *b*X and its polymonials where Y is total branches (#/plant) and X is the emergence count (#/m^2), n=24.

[§] **, significant at P≤0.01.

[Y] Standard error bracketed.


Tobin 1985
Total branches (#/plant)
70
60
50
40
30
20
10
0
0
25
50
75
100
125
150
175
200
225
Canola emergence count (#/m^2)


Westar 1985
Total branches (#/plant)
70
60
50
40
30
20
10
0
0
25
50
75
100
125
150
175
200
225
Canola emergence count (#/m^2)


Tobin 1986
Total branches (#/plant)
70
60
50
40
30
20
10
0
0
25
50
75
100
125
150
175
200
225
Canola emergence count (#/m^2)

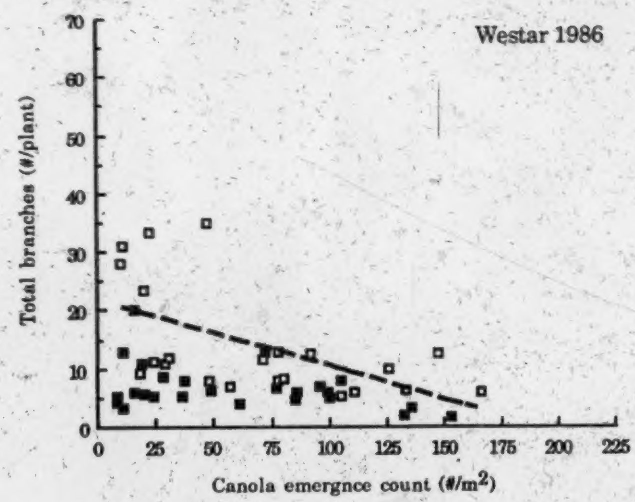

Westar 1986
Total branches (#/plant)
70
60
50
40
30
20
10
0
0
25
50
75
100
125
150
175
200
225
Canola emergnce count (#/m^2)

Table 2. Mean canola primary, secondary and tertiary branch counts.

Year	Cultivar	Barley	1^0 Branches (#/plant)	2^0 Branches (#/plant)	3^0 Branches[†] (#/plant)
1985	Tobin	Absent	4.6 (0.2)[§]	3.5 (0.3)	1.1 (0.3)
		Present	4.0 (0.1)	2.4 (0.2)	0.3 (0.08)
	Westar	Absent	3.9 (0.3)	1.3 (0.2)	0.1 (0.05)
		Present	3.1 (0.2)	1.0 (0.1)	0.1 (0.03)
1986	Tobin	Absent	6.5 (0.3)	11.7 (1.1)	5.3 (1.2)
		Present	4.0 (0.2)	2.7 (0.3)	0.4 (0.09)
	Westar	Absent	6.4 (0.3)	6.8 (1.3)	1.0 (0.3)
		Present	4.8 (0.3)	1.3 (0.3)	0.1 (0.03)

[†] Plants may have had more than tertiary branches.

[§] Standard error of the mean bracketed, n=24.

Figure 4. Relationship between seed yield and canola emergence count for Tobin and Westar, grown alone (open symbols, broken lines) and with barley (closed symbols, solid lines) in 1985 and 1986.

			Regression coefficients[†]			
Year	Cultivar	Barley	*a*	*b*	R^2	Significance[§]
1985	Tobin	Absent	$-8.91x10^{-3}$	$4.54x10^{-3}$ ($3.04x10^{-4}$)[Y]	0.91	**
		Present	$3.02x10^{-1}$	$5.64x10^{-3}$ ($6.71x10^{-4}$)	0.76	**
	Westar	Absent	$-7.37x10^{-2}$	$5.22x10^{-3}$ ($3.46x10^{-4}$)	0.91	**
		Present	$2.14x10^{-1}$	$6.65x10^{-3}$ ($7.67x10^{-4}$)	0.77	**
1986	Tobin	Absent	$-3.31x10^{-3}$	$4.17x10^{-3}$ ($5.17x10^{-4}$)	0.75	**
		Present[Ω]	4.71	1.05 (0.14)	0.72	**
	Westar	Absent	$-2.62x10^{-1}$	$1.42x10^{-2}$ ($3.18x10^{-3}$)	0.47	**
		Present	$7.09x10^{-1}$	$1.20x10^{-2}$ ($2.51x10^{-3}$)	0.51	**

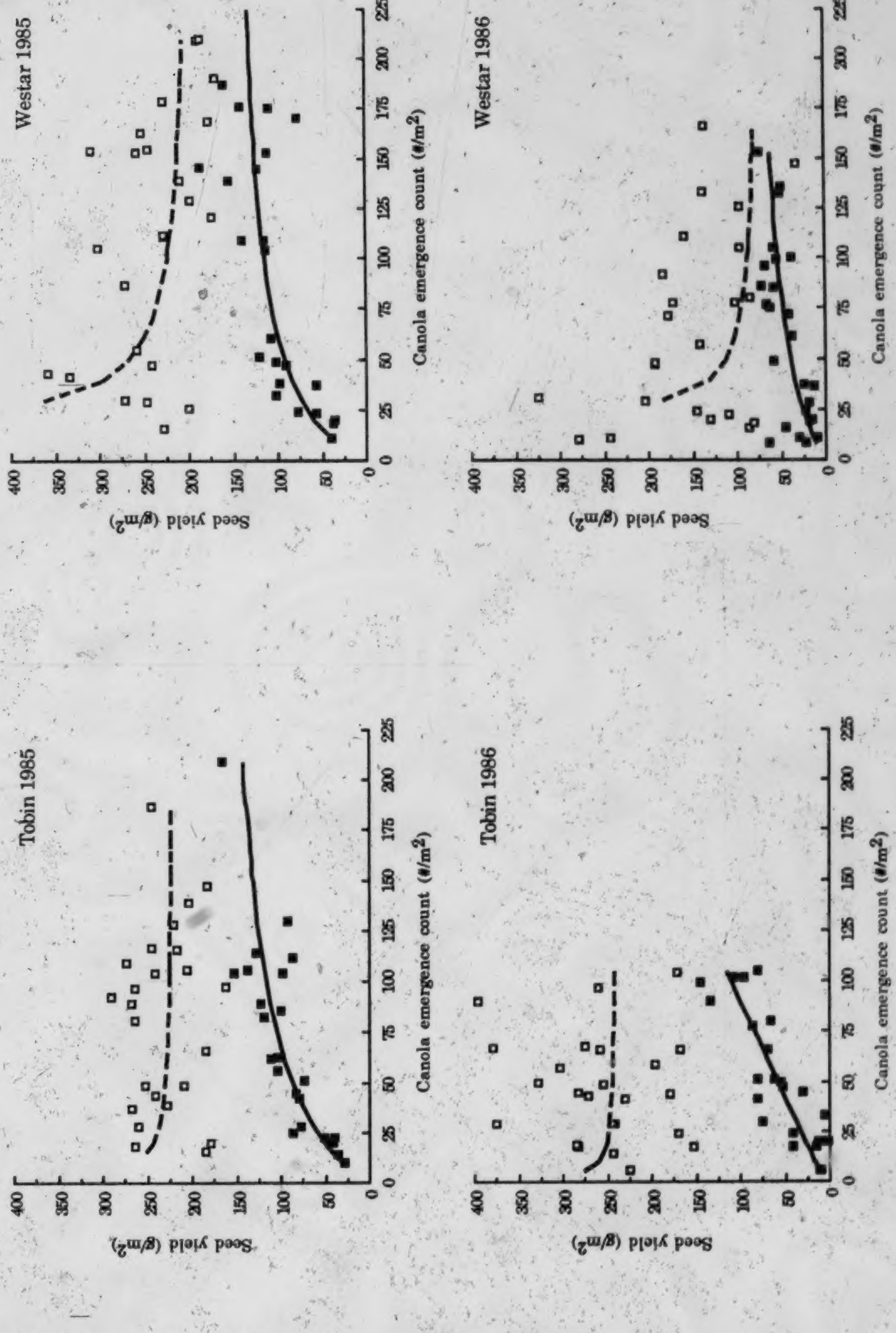
		Slope (*b*) comparisons					Significance
Year	Cultivar	Barley		Year	Cultivar	Barley	
1985	Tobin	Absent	vs	1985	Tobin	Present	**
1985	Tobin	Absent	vs	1986	Tobin	Absent	**
1985	Westar	Absent	vs	1985	Westar	Present	**
1986	Westar	Absent	vs	1986	Westar	Present	**
1985	Westar	Absent	vs	1986	Westar	Absent	**
1985	Westar	Present	vs	1986	Westar	Present	**
1985	Tobin	Absent	vs	1985	Westar	Absent	**
1986	Tobin	Absent	vs	1986	Westar	Absent	**

[†] Following the model, $X/Y=a + bX$ where Y is the seed yield (g/m^2) and X is the emergence count ($\#/m^2$), n=24.

[§] **, significant at $P \leq 0.01$.

[Y] Standard error bracketed.

[Ω] Following the model, $Y=a + bX$ where Y is the seed yield (g/m^2) and X is the emergence count ($\#/m^2$), n=24.


Westar 1985
Westar 1986
Tobin 1985
Tobin 1986
Seed yield (g/m²)
0
50
100
150
200
250
300
350
400
Canola emergence count (#/m²)
0
25
50
75
100
125
150
175
200
225

matter base for future seed yield had been constructed by Westar, but the seed yield potential was not achieved.

Canola seed yield was reduced by more than 60% when the crop was grown with barley (Figure 4). The addition of barley to the plant population was not the same as adding a similar number of canola plants. Canola grown in a canola-barley mixture yielded less than the same number of canola plants grown in a pure stand.

The benefit of a good crop stand (high plant count) under weedy conditions was evident. While the barley density was held constant, canola yield increased with canola plant density. Large gains in yield can be expected from the addition of extra canola seed to assure a good plant stand. For instance, based on the 1985 equations, yield increased 34% in both Tobin and Westar when the canola plant population was doubled from 25 to 50 plants/m^2. Yield realized by the addition of 25 canola plants to a population of 100 plants/m^2 would only be 7%.

One might expect that the ability to maintain yield on an area basis, as plant density increases, might also help maintain yield when grown in a mixture. This was not the case for Tobin growing in the presence of barley. The percent yield loss in Tobin and Westar, based on weed-free values at selected crop densities, was similar in 1985. In 1986, the percent yield loss in Tobin was higher than in Westar (Table 3).

Harvest index, the portion of total dry matter that is in the seed, was not influenced consistently by the seeding rate of canola in this experiment. Harvest indices were generally higher in 1985 than in 1986 (Figure 5). A shorter growing season at Lacombe in 1986 could account for the lower values, especially for the longer-season cultivar, Westar.

While potential yield sites are influenced by the extent of branching, the three components more directly related to actual seed yield are pod number, seeds per pod and seed weight. Of these, pod number was the yield component most responsive to plant density. Under weed-free conditions pod number declined as plant density increased (Figure 6). This corresponded to the reduction in branching that was observed (Figure 3).

Tobin and Westar grown alone had more pods per plant in 1986 than in 1985. Tobin pod number/plant declined more rapidly with increasing density in 1986 than in 1985.

In the presence of barley, pod number per plant in Tobin remained constant as plant density increased (Figure 6). Actual pod numbers per plant averaged 89.1±5 in

Table 3. Canola yield and percent yield loss[†] based on the prediction equations.

			Canola density (#/m^2)[§]			
Year	Cultivar	Barley	40	80	120	160
			Canola yield (g/m^2)			
1985	Tobin	Absent	232	226	224	223
		Present	76 (67)	106 (53)	123 (45)	133 (40)
1985	Westar	Absent	296	233	217	210
		Present	83 (72)	107 (54)	119 (45)	125 (40)
1986	Tobin	Absent	235	237	-[Y]	-
		Present[Ω]	47(80)	89 (63)	-	-
1986	Westar	Absent	131	92	83	80
		Present	34 (74)	48 (48)	56 (33)	61 (24)

[†] Weedy percent yield loss values calculated using the predicted weed-free yield for each density.

[§] Percent yield loss bracketed.

[Y] Density out of range for the equation.

[Ω] Values from a simple regression equation, canola seed yield (g/m^2)=4.71+1.05 x canola emergence count (#/m^2), R^2=0.72.

Figure 5. Relationship between harvest index and canola emergence count for Tobin and Westar, grown alone (open symbols, broken lines) and with barley (closed symbols, solid lines) in 1985 and 1986.

			Regression coefficients[†]			
Year	Cultivar	Barley	*a*	*b*	R^2	Significance[§]
1985	Tobin	Absent	no relationship			
		Present	no relationship			
	Westar	Absent	24.62	-2.62×10^{-2} (6.68×10^{-3})[¥]	0.41	**
		Present	25.01	-2.26×10^{-2} (9.34×10^{-3})	0.21	*
1986	Tobin	Absent	no relationship			
		Present	15.47	9.78×10^{-2} (1.99×10^{-2})	0.55	**
	Westar	Absent	no relationship			
		Present	no relationship			

Slope (*b*) comparisons							Significance
Year	Cultivar	Barley		Year	Cultivar	Barley	
1985	Westar	Absent	vs	1985	Westar	Present	**

[†] Following the model, $Y=a+bX$ where Y is the harvest index (%) and X is the emergence count (#/m^2), n=24.

[§] *, significant at $P\leq0.05$; **, significant at $P\leq0.01$.

[¥] Standard error bracketed.

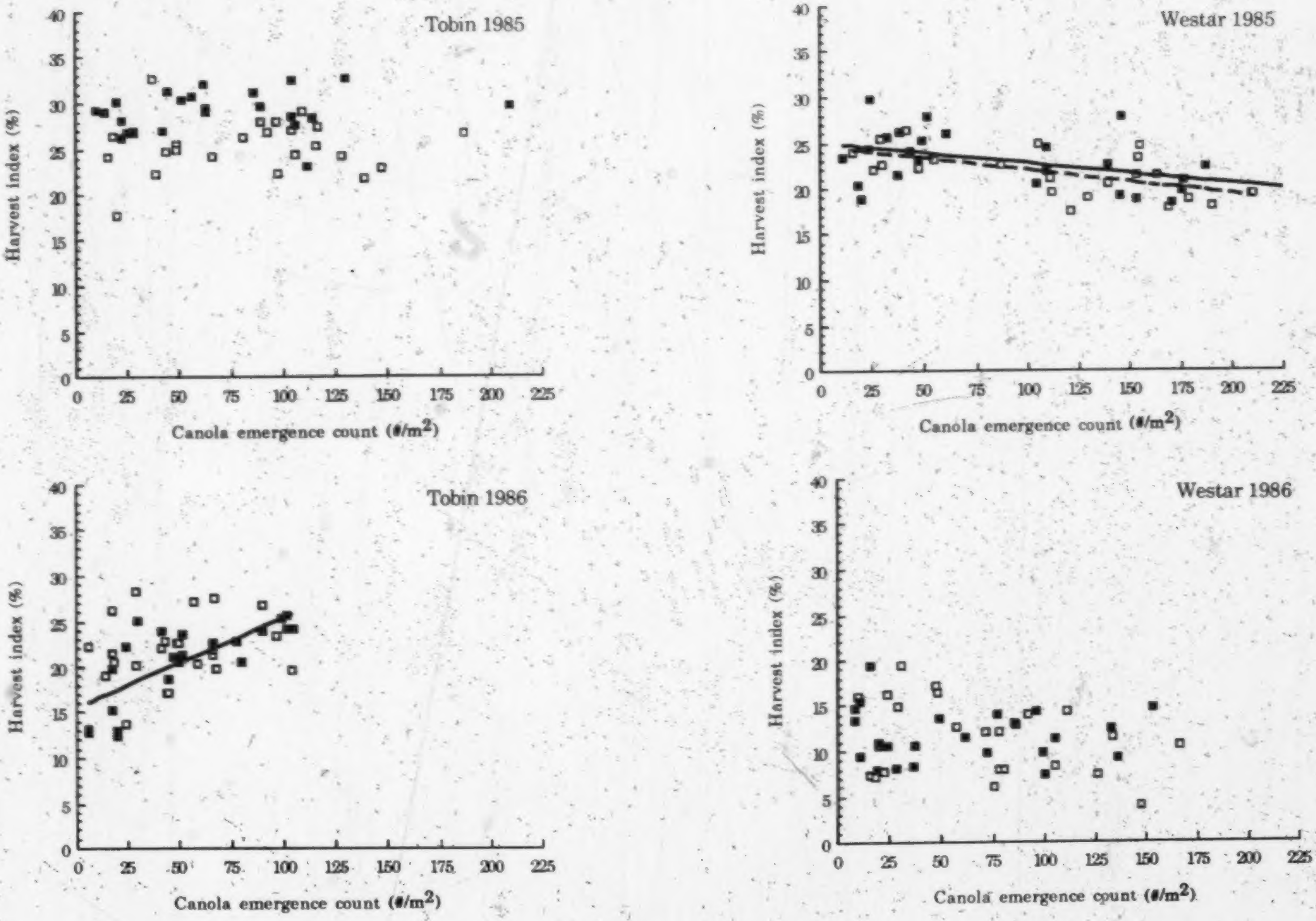

Tobin 1985
Westar 1985
Tobin 1986
Westar 1986
Harvest index (%)
Canola emergence count (#/m²)
0
5
10
15
20
25
30
35
40
0
25
50
75
100
125
150
175
200
225

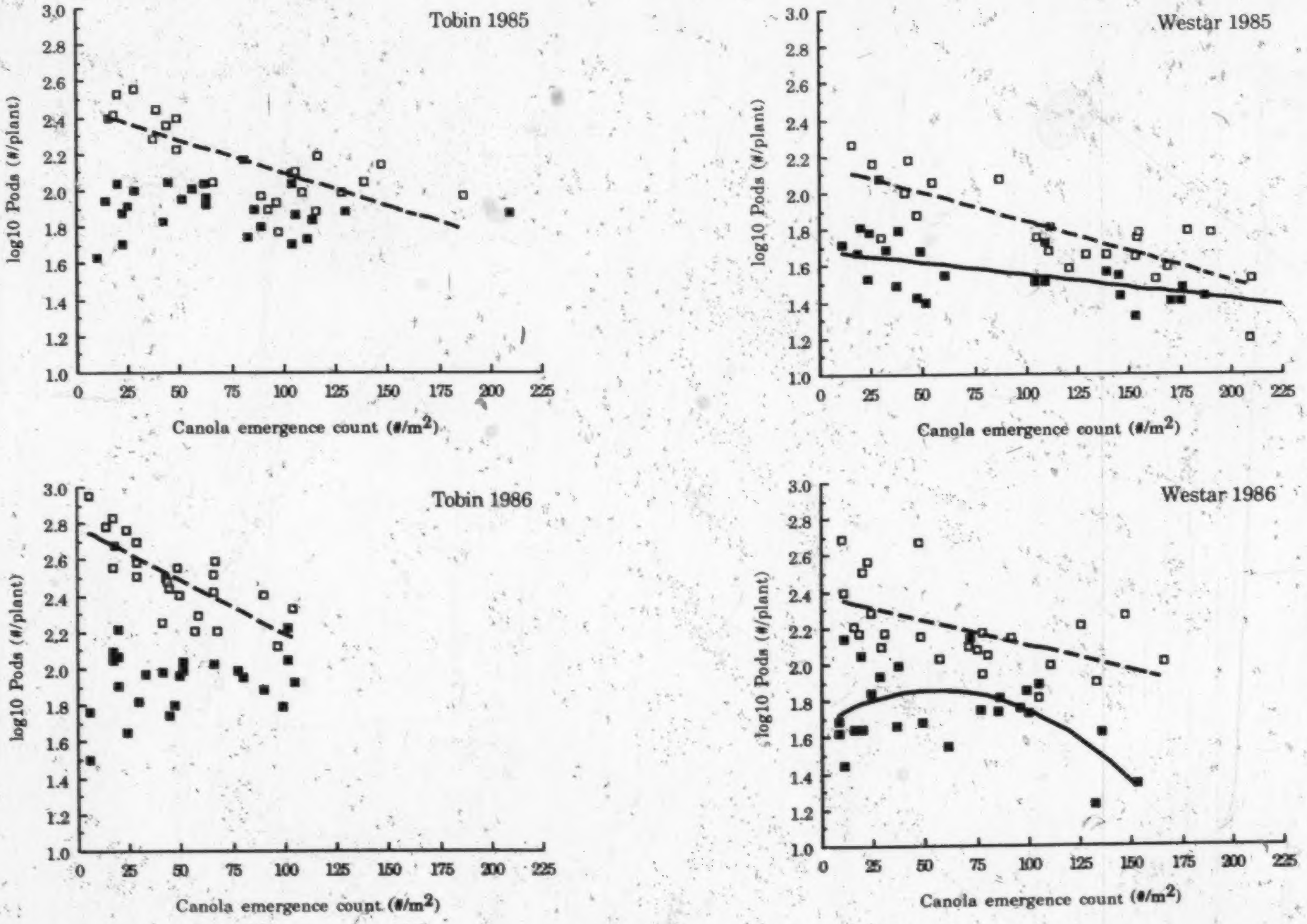
Figure 6. Relationship between $\log_{10}$ pods and canola emergence count for Tobin and Westar, grown alone (open symbols, broken lines) and with barley (closed symbols, solid lines) in 1985 and 1986.

Year	Cultivar	Barley	Regression coefficients[†] *a*	 *b*	 *c*	R^2	Significance[§]
1985	Tobin	Absent	2.46	$-3.59x10^{-3}$ $(6.75x10^{-4})$[Y]		0.56	**
		Present	no relationship				
	Westar	Absent	2.16	$-3.22x10^{-3}$ $(5.00x10^{-4})$		0.65	**
		Present	1.68	$-1.35x10^{-3}$ $(3.57x10^{-4})$		0.39	**
1986	Tobin	Absent	2.79	$-5.95x10^{-3}$ $(1.11x10^{-3})$		0.57	**
		Present	no relationship				
	Westar	Absent	2.38	$-2.79x10^{-3}$ $(8.89x10^{-4})$		0.31	*
		Present	1.67	$6.28x10^{-3}$ $(3.39x10^{-3})$	$-5.64x10^{-5}$ $(2.30x10^{-5})$	0.31	*

[†] Following the model, $Y=a + bX$ and its polynomials where Y is $\log_{10}$ pods (#/plant) and X is the emergence count (#/m^2), n=24.

[§] *, significant at $P \leq 0.05$; **, significant at $P \leq 0.01$.

[Y] Standard error bracketed.


Tobin 1985
Westar 1985
Tobin 1986
Westar 1986
log10 Pods (#/plant)
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
Canola emergence count (#/m^2)
0
25
50
75
100
125
150
175
200
225

1985 and 104.2±8 in 1986. They represented a 49 and 73% reduction from the mean weed-free pod numbers in 1985 and 1986, respectively.

Weedy Westar exhibited a gradual decline in pod number per plant as plant population increased in 1985. In 1986, however, pod number did not appear to decline until there were at least 75 Westar plants/m^2 growing with the barley.

Pod number per Tobin plant varied little when barley was present. This alone can account for the increase in seed yield as canola density increased. However, the number of seeds per pod and seed weight should also be examined as factors contributing to the seed yield. As was the case with pod number, little relationship between seeds per pod and plant density could be established (Figure 7). The number of seeds per pod was relatively constant over the two years and in the presence or absence of barley. Tobin averaged 13 seeds per pod in 1985 (weed-free 13.5±0.3, weedy 12.6±0.3) and 12 seeds per pod in 1986 (weed-free 12.1±0.3, weedy 11.8±0.4).

The size of Tobin individual seeds increased with plant population in the presence of barley (Figure 8). This suggests that while the pod and seed numbers per Tobin plant remained relatively constant over the canola densities used, there was somehow extra photoassimilate available at the higher plant densities. Pod location in the canopy could account for this phenomenon. The canola plants that had been seeded at higher densities tended to carry most of their pods on the terminal raceme where there was less shading (pers. observation).

On the whole, there were more seeds per pod in Westar than in Tobin but the number of seeds per pod was more variable (Figure 7). There were an average of 20±0.6 seeds per pod in 1985 and only 17±0.6 in 1986.

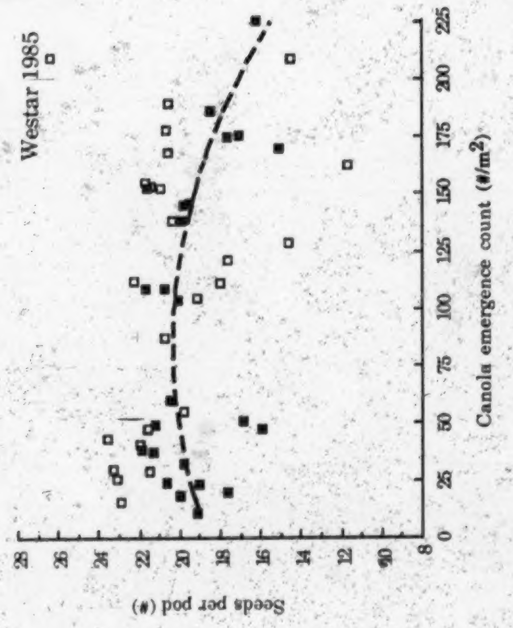
As in Tobin, the addition of barley to the plant population did not alter seed production of Westar greatly (Figures 7 and 8). Unlike Tobin, the size of the individual Westar seeds was variable. Characteristic of the species, the Westar seeds were much larger than the Tobin seeds (approximately 1 g/1000 seeds) in 1985. However, the Westar seeds were much lighter in 1986; they weighed nearly 0.5g per 1000 seeds less than Tobin seeds. This indicated that the Westar seeds were poorly filled in 1986 which no doubt accounts for the poor yield of Westar in that year.

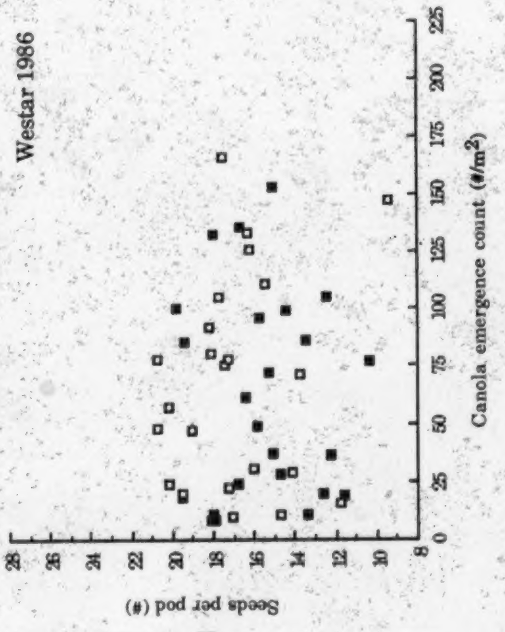
Stepwise regression was used to identify the importance of individual yield components (branching, number of pods, seeds per pod, 1000-seed weight) to individual plant yield (Table 4). The components of seed yield accounted for almost all the variability in individual plant seed yield. In all cases the order in which the

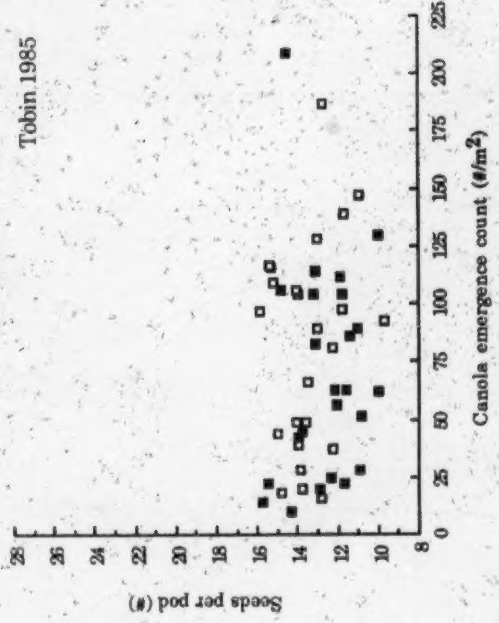
Figure 7. Relationship between seeds per pod and canola emergence count for Tobin and Westar, grown alone (open symbols, broken lines) and with barley (closed symbols, solid lines) in 1985 and 1986.

1985

Westar seeds/pod = 18.57 + (4.06 x10^{-3} x canola emergence count) - (2.40 x 10^{-4} x canola emergence count^{2}), R^2=0.28


Westar 1985
Seeds per pod (#)
28
26
24
22
20
18
16
14
12
10
8
0
25
50
75
100
125
150
175
200
225
Canola emergence count (#/m²)


Westar 1986
Seeds per pod (#)
28
26
24
22
20
18
16
14
12
10
8
0
25
50
75
100
125
150
175
200
225
Canola emergence count (#/m²)


Tobin 1985
Seeds per pod (#)
28
26
24
22
20
18
16
14
12
10
8
0
25
50
75
100
125
150
175
200
225
Canola emergence count (#/m²)

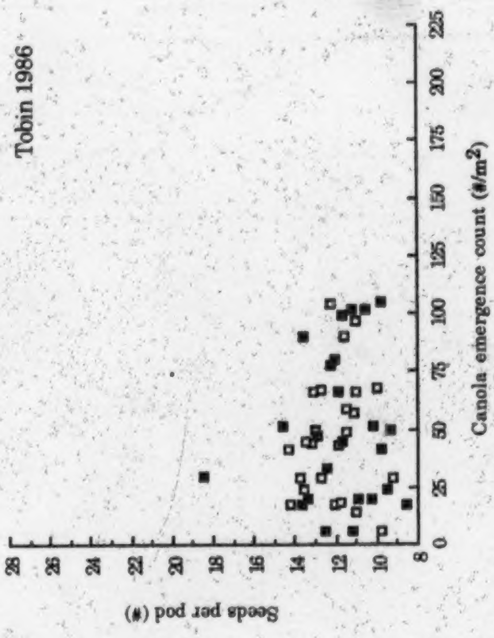

Tobin 1986
Seeds per pod (#)
28
26
24
22
20
18
16
14
12
10
8
0
25
50
75
100
125
150
175
200
225
Canola emergence count (#/m²)

Figure 8. Relationship between 1000-seed weight and canola emergence count for Tobin and Westar, grown alone (open symbols, broken lines) and with barley (closed symbols, solid lines) in 1985 and 1986.

			Regression coefficients[†]					
Year	Cultivar	Barley	*a*	*b*	*c*	*d*	R^2	Significance[§]
1985	Tobin	Absent	no relationship					
		Present	2.47	$2.98x10^{-3}$			0.34	**
				$(8.88x10^{-4})^{Y}$				
	Westar	Absent	no relationship					
		Present	2.99	$4.16x10^{-2}$	$-4.20x10^{-4}$	$1.13x10^{-6}$	0.40	**
				$(1.27x10^{-2})$	$(1.24x10^{-4})$	$(3.47x10^{-7})$		
1986	Tobin	Absent	2.17	$4.80x10^{-3}$			0.19	*
				$(2.11x10^{-3})$				
		Present	2.52	$3.43x10^{-3}$			0.20	*
				$(1.45x10^{-3})$				
	Westar	Absent	1.13	$4.36x10^{-2}$	$-4.81x10^{-4}$	$1.51x10^{-6}$	0.50	**
				$(1.33x10^{-2})$	$(1.83x10^{-4})$	$(7.03x10^{-7})$		
		Present	no relationship					

[†] Following the model, $Y=a+bX$ and its polynomials where Y is 1000-seed weight (g) and X is the emergence count (#/m^2), n=24.

[§] *, significant at $P\leq0.05$; **, significant at $P\leq0.01$.

[Y] Standard error bracketed.

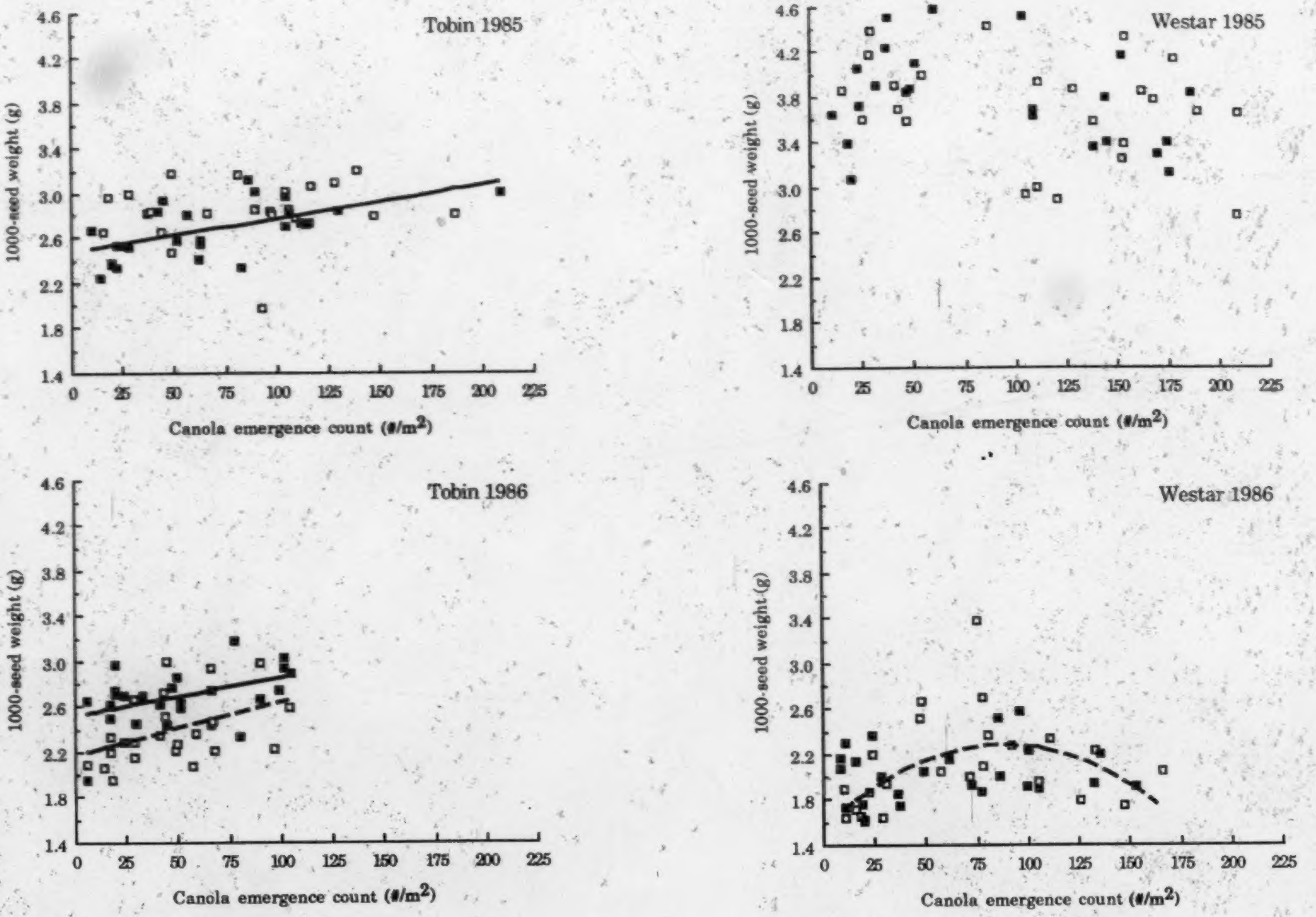

Tobin 1985
Westar 1985
Tobin 1986
Westar 1986
1000-seed weight (g)
4.6
4.2
3.8
3.4
3.0
2.6
2.2
1.8
1.4
0
25
50
75
100
125
150
175
200
225
Canola emergence count (#/m^2)

Table 4. Intercepts and stepwise linear regression coefficients for $\log_{10}$ (canola seed weight +1) and the components of yield on a per plant basis.

Year	Cultivar	Barley	Regression coefficients†					R^2	Significance§
			a	*b*	*c*	*d*	*e*		
1985	Tobin	Absent	-1.65	8.47x10^{-1} (1.18x10^{-2})Y	2.66x10^{-2} (1.77x10^{-3})	9.85x10^{-2} (9.58x10^{-3})		0.99	**
		Present	-1.43	7.27x10^{-1} (1.89x10^{-2})	2.55x10^{-2} (1.40x10^{-3})	1.07x10^{-1} (9.35x10^{-3})		0.99	**
	Westar	Absent	-1.16	6.84x10^{-1} (6.32x10^{-2})	1.83x10^{-2} (2.69x10^{-3})	7.17x10^{-2} (1.86x10^{-2})	1.28x10^{-2} (5.41x10^{-3})	0.98	**
		Present	-1.13	7.30x10^{-1} (2.39x10^{-2})	1.31x10^{-2} (1.92x10^{-3})	7.98x10^{-2} (8.20x10^{-3})		0.99	**
1986	Tobin	Absent	-1.91	8.72x10^{-1} (1.01x10^{-2})	3.41x10^{-2} (1.50x10^{-3})	1.33x10^{-1} (7.32x10^{-3})		0.99	**
		Present	-1.22	6.86x10^{-1} (3.17x10^{-2})	1.73x10^{-2} (2.16x10^{-3})	9.86x10^{-2} (2.19x10^{-2})		0.98	**
	Westar	Absent	-1.68	7.69x10^{-1} (3.73x10^{-2})	2.33x10^{-2} (1.43x10^{-3})	1.80x10^{-1} (1.25x10^{-2})	2.21x10^{-3} (9.21x10^{-4})	0.99	**
		Present	-0.88	4.33x10^{-1} (7.34x10^{-2})	1.32x10^{-2} (1.71x10^{-3})	1.45x10^{-1} (3.03x10^{-2})	1.30x10^{-2} (5.59x10^{-3})	0.97	**

† Following the model, $Y=a + bLP + cSP + dSW + eBR$ where Y is the $\log_{10}$(seed weight+1); LP, log10 pods/plant; SP, seeds/pod; SW, 1000-seed weight; BR, total branches/plantt, n=24.

§ **, significant at $P<0.01$.

Y Standard error bracketed.

components were entered into the equations was pod number, seeds per pod, 1000-seed weight, total number of branches. The number of pods per plant was the most important component of Tobin and Westar yield, based on the relative size of the standard partial regression coefficients (Table 5). In fact, seed yield could easily be explained by pod number alone. Generally, the second most important factor was the number of seeds per pod. There were instances where seed size, as described by 1000-seed weight, was more important than seeds per pod. This occurred in weedy Westar, 1985 and weed-free Westar 1986. This could be interpreted to mean that there were plenty of seeds to fill, but a lack of photosynthate to fill the seeds properly. Total branch count was not a significant factor contributing to seed yield of Tobin. When total branches were entered into the Westar equations, this component accounted for very little of the variability in seed yield.

In this experiment, the effect of barley on yield components and seed yield of canola was similar to that caused by increasing plant density, without the contribution made by the additional plants. At low canola populations, barley alone was responsible for the reduced number of branches and pods while at higher plant densities, competition between the canola plants themselves became a factor.

Insight into plant competition can be derived by examination of the equations used to describe the reciprocal of per plant total weight and canola density. Under pure stand conditions, the intercept (*a*) is the reciprocal of the total weight of an isolated plant where no inter-plant competition is occurring (Spitters, 1983a). The negative estimates of the intercept for Tobin and Westar grown alone (Figure 9) are caused by random errors. In all cases, positive intercepts were possible considering the standard errors (not shown) obtained for the parameter in each equation. The slope (*b*) measures how the reciprocal of the total weight increases, in other words, how the weight per plant declines as plant density increases. The decrease in weight per plant varied between mono-cropped Tobin and Westar and between years. In 1985, this decline was similar in both cultivars while in 1986, there was a larger decrease in weight per plant in Westar than Tobin as plant density increased. The ratio of *b/a* is used to measure intra-specific competition. Based on absolute values of the slope/intercept ratio, competition between Tobin or Westar plants grown alone differed between the two cultivars and years. Intra-specific competition in Westar was greater than in Tobin in both years. Competition between the canola plants was more severe in 1985 than in

Table 5. Standardized partial regression coefficients from stepwise linear regression models on $\log_{10}$ (canola seed weight +1) and the components of yield on a per plant basis.

				Components of yield†					
Year	Cultivar	Barley	Step	$\log_{10}$ pods (#/plant)	Seeds/ pod (#)	1000-seed weight (g)	Total branches (#/plant)	R^2	SE§
1985	Tobin	Absent	1	0.97				0.93	0.06
			2	0.92	0.24			0.98	0.03
			3	0.93	0.20	0.13		0.99	0.01
		Present	1	0.91				0.75	0.04
			2	0.96	0.42			0.91	0.03
			3	0.97	0.46	0.29		0.99	0.01
	Westar	Absent	1	0.98				0.93	0.07
			2	0.85	0.23			0.97	0.05
			3	0.80	0.22	0.11		0.98	0.04
			4	0.68	0.23	0.13	0.13	0.98	0.03
		Present	1	0.91				0.82	0.05
			2	0.94		0.38		0.99	0.03
			3	0.85	0.21	0.28		0.99	0.01

../2

Table 5. (Continued).

Year	Cultivar	Barley	Step	Components of yield: $\log_{10}$ pods (#/plant)	Components of yield: Seeds/ pod (#)	Components of yield: 1000-seed weight (g)	Components of yield: Total branches (#/plant)	R^2	SE
1986	Tobin	Absent	1	0.92				0.88	0.07
			2	0.90	0.29			0.99	0.04
			3	0.96	0.25	0.20		0.99	0.01
		Present	1	0.97				0.90	0.04
			2	1.00	0.25			0.95	0.03
			3	0.90	0.28	0.19		0.98	0.02
	Westar	Absent	1	0.88				0.76	0.11
			2	0.86	0.42			0.94	0.06
			3	0.93	0.30	0.36		0.99	0.02
			4	0.84	0.31	0.36	0.10	0.99	0.02
		Present	1	0.86				0.70	0.08
			2	0.94	0.50			0.93	0.04
			3	0.91	0.39	0.20		0.96	0.03
			4	0.66	0.39	0.23	0.25	0.97	0.03

† Following the model, $Y=a + bX_1 + cX_2 + dX_3 + eX_4$ where Y is the seed yield (g/plant) and X_1, X_2, X_3, X_4 are components of seed yield, n=24.

§ SE, square root of error mean square.

Figure 9. Relationship between plant emergence count and the reciprocal of plant total weight of canola and barley.

Canola grown alone:

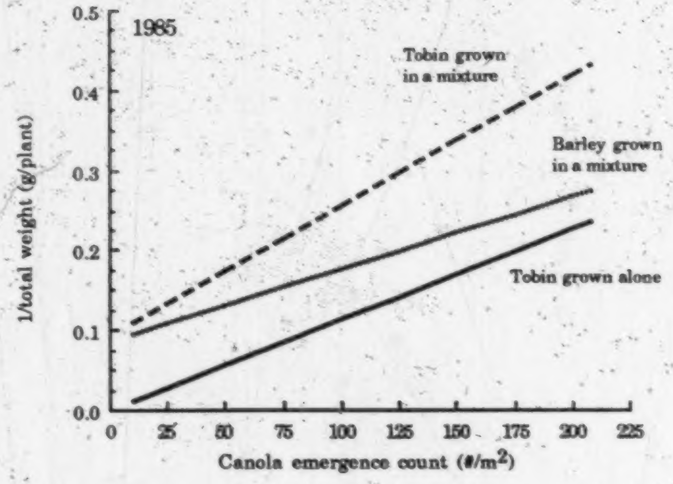
		Regression coefficients[†]				
Year	Cultivar	*a*	*b*	*b/a*	R^2	Significance[§]
1985	Tobin	-1.78×10^{-3}	1.13×10^{-3} (4.63×10^{-5})[Y]	-0.63	0.96	**
	Westar	-6.45×10^{-3}	9.90×10^{-4} (4.30×10^{-5})	-0.15	0.96	**
1986	Tobin	-5.00×10^{-4}	8.86×10^{-4} (7.04×10^{-5})	-0.18	0.88	**
	Westar	-2.48×10^{-2}	1.55×10^{-3} (4.60×10^{-4})	-0.06	0.34	**

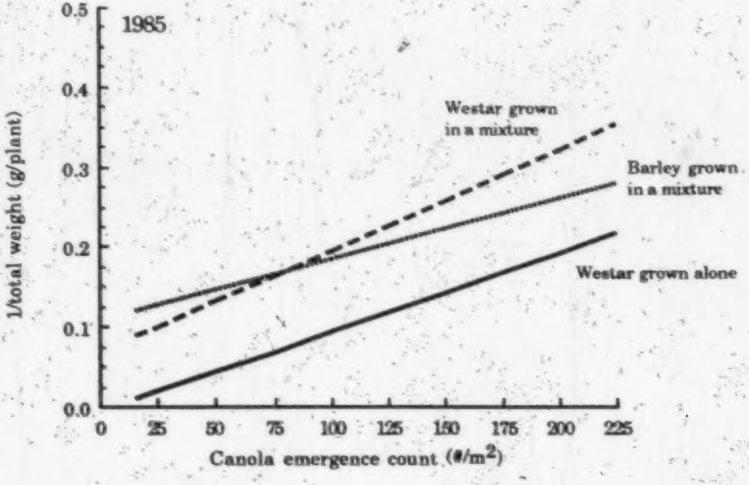
[†] Following the model, $1/Y=a+bX$ where Y is the canola total weight (g/plant) and X is the canola emergence count ($\#/m^2$), n=24.
[§] **, significant at $P\leq0.01$.
[Y] Standard error bracketed.

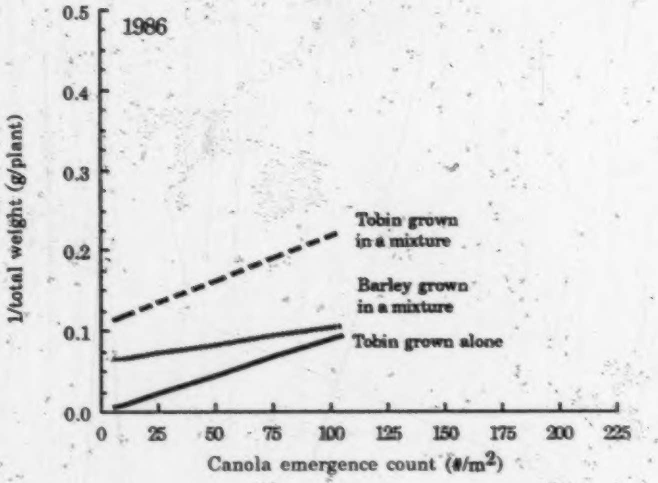
Mixtures:

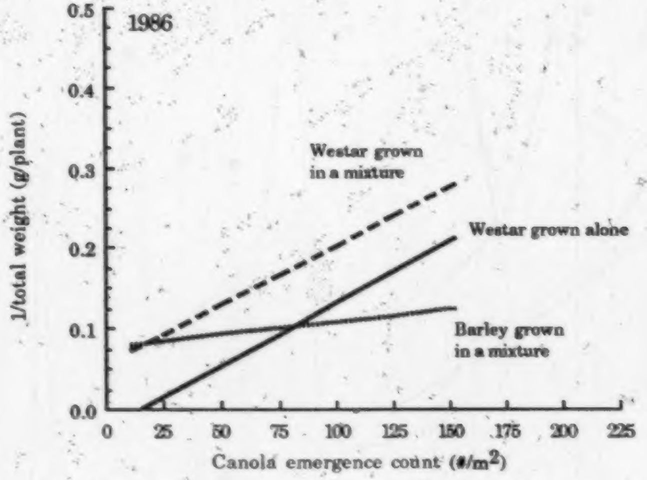
		Regression coefficients					
Year	Cultivar	*a*	*b*	*c*	*b/c*	R^2	Significance[†]
Canola grown with barley[§]:							
1985	Tobin	6.08×10^{-2}	1.63×10^{-3} (1.60×10^{-4})[Y]	3.76×10^{-4} (9.18×10^{-4})	4.34	0.83	**
	Westar	2.62×10^{-2}	1.27×10^{-3} (1.09×10^{-4})	5.13×10^{-4} (8.66×10^{-4})	2.48	0.87	**
1986	Tobin	-1.65×10^{-1}	1.11×10^{-3} (3.63×10^{-4})	3.38×10^{-3} (1.06×10^{-3})	0.33	0.46	**
	Westar	-6.63×10^{-2}	1.47×10^{-3} (1.67×10^{-4})	1.51×10^{-3} (8.57×10^{-4})	0.97	0.80	**
Barley grown with canola[Ω]:							
1985	Barley in Tobin	8.90×10^{-2}	9.05×10^{-4} (1.21×10^{-4})	-6.06×10^{-5} (6.92×10^{-4})	-14.93	0.79	**
	Barley in Westar	7.81×10^{-2}	7.66×10^{-4} (1.24×10^{-4})	3.63×10^{-4} (9.82×10^{-4})	2.11	0.65	**
1986	Barley in Tobin	-9.17×10^{-3}	4.16×10^{-4} (6.22×10^{-5})	8.78×10^{-4} (1.82×10^{-4})	0.47	0.75	**
	Barley in Westar	3.42×10^{-2}	3.14×10^{-4} (3.72×10^{-5})	5.30×10^{-4} (1.91×10^{-4})	0.59	0.80	**

[†] **, significant at $P\leq0.01$.
[§] Following the model, $1/Y=a+bX+cZ$ where Y is the canola total weight (g/plant) and X is the canola emergence count ($\#/m^2$), and Z is the barley emergence count ($\#/m^2$), n=24.
[Y] Standard error bracketed.
[Ω] Following the model, $1/Y=a+bX+cZ$ where Y is the barley total weight (g/plant) and X is the canola emergence count ($\#/m^2$), and Z is the barley emergence count ($\#/m^2$), n=24.


1985
Tobin grown in a mixture
Barley grown in a mixture
Tobin grown alone
1/total weight (g/plant)
0.0
0.1
0.2
0.3
0.4
0.5
0
25
50
75
100
125
150
175
200
225
Canola emergence count (#/m²)


1985
Westar grown in a mixture
Barley grown in a mixture
Westar grown alone
1/total weight (g/plant)
0.0
0.1
0.2
0.3
0.4
0.5
0
25
50
75
100
125
150
175
200
225
Canola emergence count (#/m²)


1986
Tobin grown in a mixture
Barley grown in a mixture
Tobin grown alone
1/total weight (g/plant)
0.0
0.1
0.2
0.3
0.4
0.5
0
25
50
75
100
125
150
175
200
225
Canola emergence count (#/m²)


1986
Westar grown in a mixture
Westar grown alone
Barley grown in a mixture
1/total weight (g/plant)
0.0
0.1
0.2
0.3
0.4
0.5
0
25
50
75
100
125
150
175
200
225
Canola emergence count (#/m²)

1986. These differences can be attributed to environmental conditions, as the two experiments were conducted in the same manner in both years.

Multiple linear regression can be used to separate intra-specific competition and inter-specific competition mathematically. The relative competitive ability of a species is defined by the relationship between the regression coefficients (*b* and *c*) The effect of adding one plant of species 1 has an equal effect on the reciprocal of per plant weight of adding *b*/*c* plants of species 2 (Spitters, 1983a). The graphs presented for the mixtures in Figure 9 are based on a fixed barley density of 80 plants/m^2. In 1985, one canola plant and 4.3 barley plants had an equal effect on the average total weight per Tobin plant. The addition of one Westar plant to the population was equivalent to adding 2.4 barley plants to the population in 1985. From the canola perspective, Tobin and Westar plants themselves were much stronger competitors than the barley in 1985. The situation was reversed in 1986 when the addition of one Tobin or Westar plant was equivalent to less than one barley plant. For the barley, the presence of one Tobin plant in 1985 was similar to the presence of 14.9 other barley plants. Westar did not affect barley weight to as large an extent as Tobin had in 1985. The addition of one Westar plant was the same as adding 2.1 barley plants, from the barley point of view. Competition in the barley was less in 1986. The addition of one Tobin or Westar plant had the same effect on barley as adding less than 0.6 barley plants.

The relationship of the ratios (*b/c*) derived from the regression equations on canola and barley biomass gives insight into the intra- and inter-specific competition occurring in the canola/barley mixture. For instance, there was more inter-specific competition than intra-specific competition in the Tobin/barley mixture in both years while the reverse was true for Westar and barley. This means that when Tobin and barley plants or Westar and barley plants are combined, they utilize available resources in a different manner. Niche differentiation can be described mathematically by expressing the ratios (*b/c*) developed earlier as double quotients (Spitters, 1983a). For example, using the Tobin and barley ratios from 1985 (ignoring the negative sign) the value would be 4.34/14.93=0.29. If this value is greater than unity, there is little niche overlap; when it is less than unity, the niches overlap considerably. Based on the results from this experiment, the Tobin and barley plants utilize many common resources, while Westar and barley do not. This implies that if barley is a weed, Tobin (*B. campestris*) would be the crop of choice as it would limit barley growth more than Westar (*B. napus*). However, if one wanted to grow barley and canola as a mixture, Westar would be better than Tobin.

SUMMARY

No optimum density for canola seed yield was observed. Under weed-free conditions, the highest yields were at the lowest plant densities (6 to 16 plants/m^2 or approximately 1 kg seed/ha). When canola was grown alone, intra-specific plant competition was greater in Westar than Tobin.

When barley was present, seed yield increased as crop density increased. There was more plant competition between Tobin and barley than Westar and barley. When barley infestations are anticipated, crop management can reduce the effects of the weed. A producer can seed canola at a higher rate than normal (4 to 8 kg/ha) and/or they can select a more competitive canola variety, such as Tobin.

The effect of barley on canola seed yield components was similar to that caused by increasing plant density in pure stands of canola. Canola branching and pod number was reduced by the presence of barley. This was important as pod number accounted for most of the variability in canola yield on a per plant basis.

CHAPTER 3

COMPETITION BETWEEN CANOLA AND BARLEY GROWN AT A RANGE OF POPULATION DENSITIES: EFFECTS ON THE CANOLA CROP AND BARLEY

INTRODUCTION

Volunteer barley can be a serious weed problem in canola-producing areas of Alberta where canola frequently follows barley in rotations. Recently, volunteer barley was found in 14% of all the fields (wheat, oat and canola) surveyed in central Alberta at an average density of 4 plants/m^2 (Pickle, 1989, pers. comm.). Volunteer barley is likely to be present in canola fields at higher densities when delayed harvesting has led to shattering the previous season.

Although volunteer cereals are a common weed problem in crops in the three prairie provinces, information dealing with yield loss due to volunteer cereals is scant. Marshall *et al.* (1989), working in Manitoba, described the relationship between wheat and barley, seeded as volunteer weeds and canola (*Brassica napus*) biomass and yield. Barley reduced canola seed yield and biomass as density increased. Barley caused greater reductions in canola yield than volunteer wheat. The difference in competitive ability of the two volunteer cereals was reflected not only in the higher canola yields when wheat was the weed but also in the proportionally lower wheat yields when compared to barley.

O'Donovan *et al.* (1987) used nonlinear rectangular hyperbola models to describe the relationship between canola (*B. campestris*) yield and barley density for experiments conducted in Alberta and Saskatchewan. Canola yield loss due to barley varied among locations. Yield loss was greatest in locations where canola yield potential was high. At high barley densities, 200 plants/m^2, canola yield was reduced up to 80%. At a moderate barley density, 25 plants/m^2, canola yield was reduced between 10 and 25%.

The first objective of this research was to determine how barley seeded at various densities affected biomass production and partitioning into seed of *B. campestris* and *B. napus* varieties. The second objective was to determine the cost-effectiveness of controlling barley in canola based on the yield-density relationships identified.

MATERIALS and METHODS

Field procedure. Field experiments were conducted at the Agriculture Canada Research Station, Lacombe, Alberta (52° 28' latitude, 113° 44' longitude) in 1984 and 1985. The plots were established on weed-free, fallowed Ponoka sandy loam soil (54% sand, 37% silt, 9% clay, OM 10%, pH 5.6) in 1984 on clean fallowed Ponoka silt loam soil (26% sand, 34% silt, 40% clay, OM 9%. pH 6.0) in 1985. The seedbed was prepared by cultivating two or three times in the spring with a vibrashank cultivator, followed by harrowing with a spike-tooth harrow.

Brassica campestris cv Tobin and *B. napus* cv Westar canola-type rapeseed were seeded as the crop and *Hordeum vulgare* cv Galt was used to simulate volunteer barley. The experiment was set out in a split-block design. Individual plots were 1.8 by 2.7 m. Percent seed germination and estimated seed vigour were factored into the seed rates for both canola and barley. Barley seeded at target densities of 0, 10, 25, 50, 75, 100, 150 and 200 plants/m^2, arranged in a completely randomized design, constituted the main effects or whole plots of this experiment. In the sub-plot treatments, Tobin or Westar canola was seeded at a target density of 200 plants/m^2 in strips that were randomized across four replications. The canola and barley were planted to emerge simultaneously. They were seeded at right angles to each other with a double-disk press-type drill, in 23-cm wide rows. The canola seeds were dressed with VITAVAX RS FLOWABLE™[1] (carbathiin[2] 1 g ai/kg seed, thiram[3] 2 g ai/kg seed, lindane[4] 15 g ai/kg seed) for flea beetle (*Phyllotreta cruciferae* Goeze, *P. striolata* Fab.) and fungal seedling disease protection prior to planting. In both years, 63 kg/ha monoammonium phosphate (11-51-0) fertilizer was applied with the canola seed.

After plant emergence, a 0.84 m^2 area was selected and marked in each plot. The following data were recorded in each quadrat: canola and barley plant counts at emergence and harvest, shoot dry weights at harvest, seed yield, 1000-seed weights for canola and 250-kernel weights for barley. Harvest indices[5] were calculated. The seeding, emergence and harvest dates are listed in Table 1.

---

[1] Uniroyal Chemical Ltd., 4-2216 27 Ave. N.E., Calgary, Alberta T2E 7A7

[2] gamma-1,2,3,4,5,6-hexachlorocyclohexane

[3] bis(dimethylthiocarbamoyl)disulfide

[4] 5,6-dihydro-2-methyl-1,4-oxathiin-3-carboxanilide

At maturity, the canola and barley plants were hand-cut approximately 5 cm above ground level and placed in large cotton bags. The samples were dried to constant weight before threshing in a stationary thresher.

Data analysis. Preliminary data analysis showed that the relationship between the canola data (shoot weight, g/m^2; seed yield, g/m^2; harvest index,%; 1000-seed weight, g) and barley emergence count was best described by simple linear or quadratic regression equations. Tests were done for parallel lines or curves to ascertain whether the canola response was the same over the varieties and years.

Preliminary regression analysis showed that the intercepts for barley shoot weight, seed yield and culm count did not differ from zero, therefore regression equations with intercepts set to zero were used. Comparisons between slopes of these equations were made following the procedure outlined in Gomez and Gomez (1984, p. 373). Barley harvest index and 250-kernel weight data were combined and analyzed by the same procedure used for the canola data. Maximum values for quadratic equations were calculated by setting the first derivative of $Y = a + bX + cX^2$ equal to zero and solving for X[6].

Inter-specific competition between the canola and barley was assessed using multiple linear regression equations Spitters (1983a). The ratio of the regression coefficients, b and c, derived from the equation; $1/Y = a + bX + cZ$, where Y = total weight per plant at harvest of either canola or barley, X=canola emergence count ($\#/m^2$) and Z=barley emergence count ($\#/m^2$), were used to explain the relative competitive ability of each species.

The relationship between plant density, seed yield and economic value was examined by combining data from the experiments in Chapters 2 and 3. Only 1985 data were used as the experiment in Chapter 2 was conducted in 1985 and 1986 while the experiment in Chapter 3 was conducted in 1984 and 1985. The plant emergence count

---

[5] $\text{Harvest index (\%)} = \frac{\text{seed yield}}{\text{seed+stem weight}} \times 100$

[6] $Y' = b - 2cX$

$0 = b - 2cX$

$X = \frac{b}{2c}$

Table 1. Dates of seeding, emergence and harvest.

Year	Canola or barley	Seeding date	Emergence date	Harvest date
1984	Tobin	May 23	May 30	Aug. 17
	Barley in Tobin	May 23	June 1	Aug. 17
	Westar	May 23	May 30	Aug. 30
	Barley in Westar	May 23	June 1	Aug. 30
1985	Tobin	May 22	May 30	Aug. 19
	Barley in Tobin	May 21	May 30	Aug. 19
	Westar	May 21	May 30	Sept. 20
	Barley in Westar	May 21	May 30	Sept. 20

data from plots in each experiment containing both canola and barley were expressed as ratios. For instance, if a plot contained 75 canola plants and 50 barley plants, the ratio for the canola would be 75/(75+50)=0.6, the barley ratio would be 0.4. Simple linear and multiple regression was then used to define the relationship between the seed yield and the plant density ratio for both barley and canola. The predicted seed yields were used to calculate the economic value of the canola/barley mixture. The Alberta Wheat Pool price for No. 1 canola ($240.51/t) and barley ($81.22/t) at the Lacombe elevator, August 28, 1989, were used in the calculations. Production cost was not considered.

RESULTS and DISCUSSION

Canola shoot weight and seed yield declined as barley density increased (Figures 1 and 2). The response curves for shoot weight and seed yield differed between the two canola cultivars but not between the two years (Tables 2 and 3).

The loss in Westar shoot dry matter per barley plant remained constant over the barley densities used in this experiment. In Tobin, both shoot weight and seed yield began to level off around 100 barley plants/m^2, suggesting that Tobin may be more density-tolerant than Westar. This supports the premise (Chapter 2) that canola plants which exhibit low intra-specific competition when grown in pure stands, maintain yield when grown in mixtures or under weedy conditions.

The reduction in shoot weight was not a result of density-dependent plant mortality. The canola plants responded to the stress exerted by the barley plants by producing smaller individual plants.

Not only were the individual canola plants smaller, in terms of dry weight, as barley density increased, but proportionally less dry matter was partitioned into seed (Figure 3). While harvest indices were higher for Tobin in 1985 than in 1984, the loss per barley plant was similar in both years. Harvest index declined approximately 0.6% for every 10 barley plants present in Tobin.

The relationship between Westar harvest index and barley differed in the two experiment-years. The range of predicted harvest indices was much larger in 1985 (8.7 to 19%) than in 1984 (19.1 to 21.0%). The very low Westar harvest indices observed at higher barley densities were likely a competition effect. Shading by the barley plants could have limited photosynthesis and thus partitioning of dry matter into seed.

In absolute terms, seed yield was less in Westar than in Tobin at any of the barley densities used (Figure 2). While *B. napus* generally yields more than *B. campestris* in areas where growing season is not limiting, this was not the case at Lacombe. The yields can not be explained solely by killing (-2 C) frost date. The highest yields occurred in 1984 when the first frost was September 2 compared to September 23 in 1985. Obviously conditions during the growing season affected the yield potential of the cultivars. Tobin requires fewer days to mature than Westar and the number of growing degree days available at Lacombe is marginal for *B. napus* production (Appendix 1).

Figure 1. Relationship between shoot weight and barley emergence count for canola (closed symbols, solid lines) and for barley (open symbols, broken lines) grown with different densities of barley in 1984 and 1985.

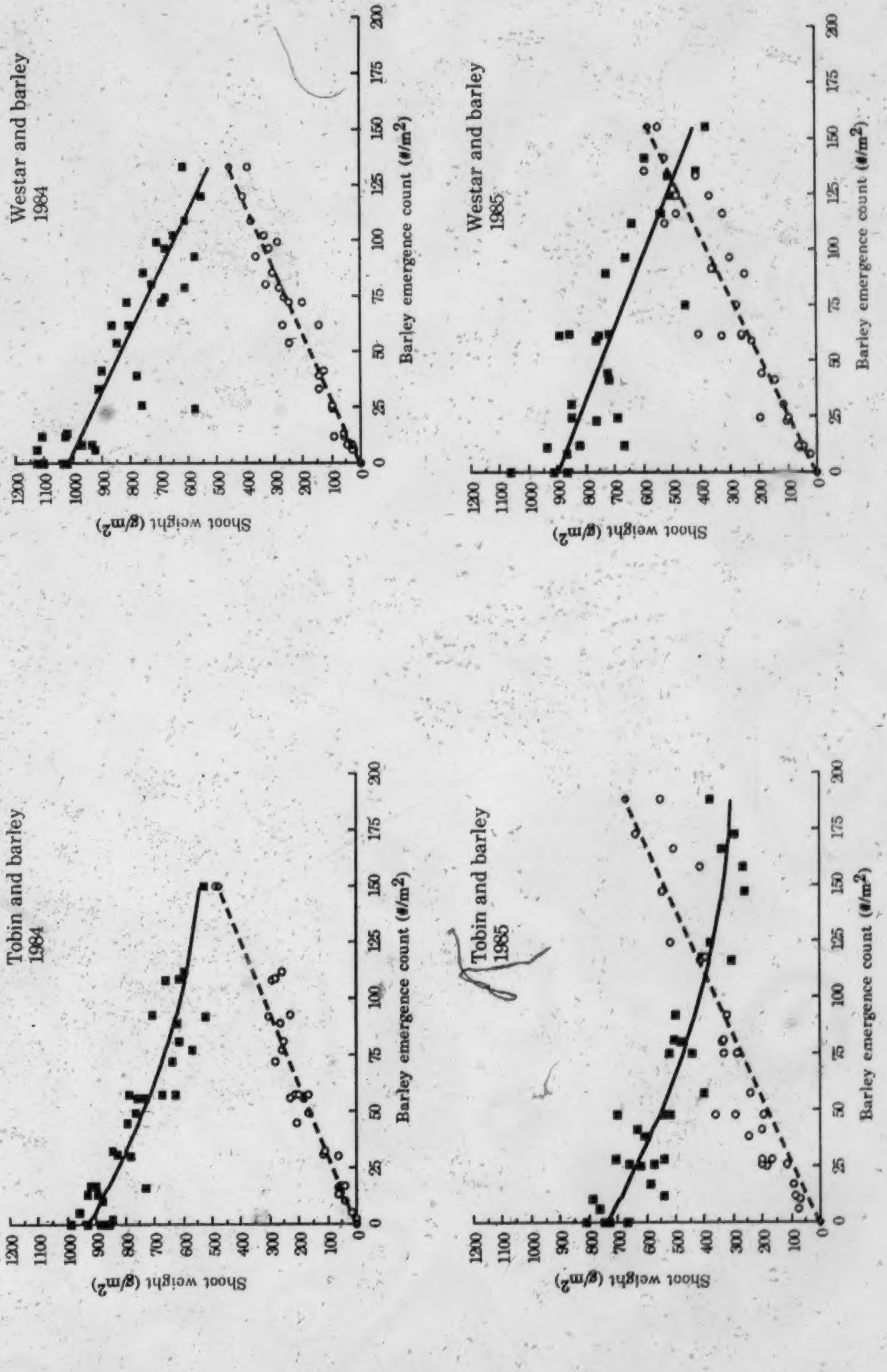
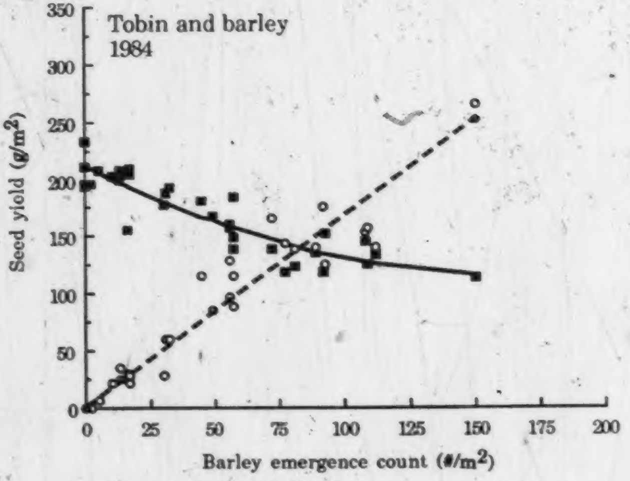
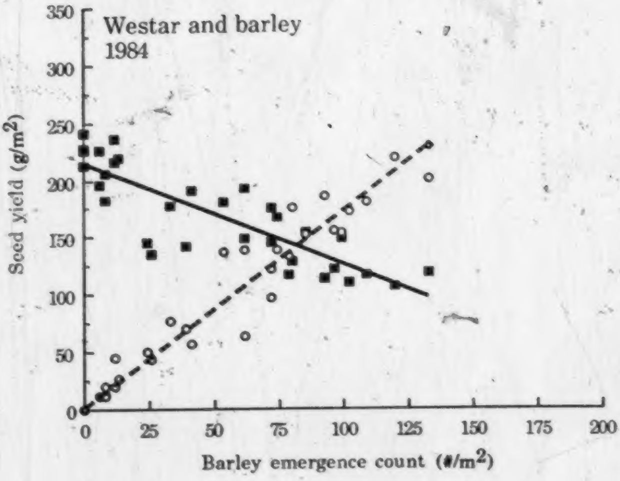
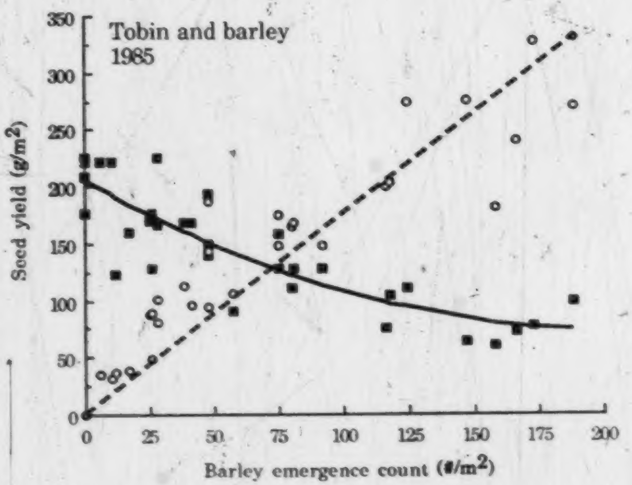

Westar and barley
1984
Westar and barley
1985
Tobin and barley
1984
Tobin and barley
1985
Shoot weight (g/m^2)
Barley emergence count (#/m^2)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
0
25
50
75
100
125
150
175
200

Figure 2. Relationship between seed yield and barley emergence count for canola (closed symbols, solid lines) and for barley (open symbols, broken lines) grown with different densities of barley in 1984 and 1985.


Tobin and barley
1984
Seed yield (g/m^2)
350
300
250
200
150
100
50
0
0
25
50
75
100
125
150
175
200
Barley emergence count (#/m^2)


Westar and barley
1984
Seed yield (g/m^2)
350
300
250
200
150
100
50
0
0
25
50
75
100
125
150
175
200
Barley emergence count (#/m^2)


Tobin and barley
1985
Seed yield (g/m^2)
350
300
250
200
150
100
50
0
0
25
50
75
100
125
150
175
200
Barley emergence count (#/m^2)

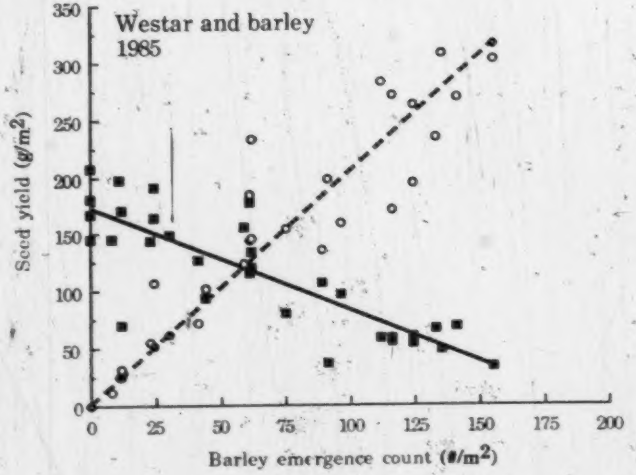

Westar and barley
1985
Seed yield (g/m^2)
350
300
250
200
150
100
50
0
0
25
50
75
100
125
150
175
200
Barley emergence count (#/m^2)

Table 2. Relationship between canola shoot weight and barley density, and comparisons of the regression lines.

		Regression coefficients[†]			
Year	Cultivar	*a*	*b*	*c*	R^2
1984	Tobin	925.89	-4.41 (0.86)[§]	$1.22x10^{-2}$ ($6.77x10^{-3}$)	0.81
	Westar	1017.22	-3.72 (0.44)		0.72
1985	Tobin	735.42	-4.29 (0.72)	$1.06x10^{-2}$($4.07x10^{-3}$)	0.73
	Westar	894.74	-3.05 (0.36)		0.71
Combined	Tobin	828.33	-3.64 (0.89)	$4.58x10^{-3}$ ($5.42x10^{-3}$)	0.63
	Westar	962.47	-3.46 (0.30)		0.68

The cultivar responses differ. Within each cultivar, the regression lines are parallel, but the intercepts differ ($P \leq 0.05$).

[†] Following the models, $Y=a + bX$ or $Y=a + bX + cX^2$ where Y is the canola shoot weight (g/m^2) and X is the barley emergence count ($\#/m^2$), n=32.

[§] Standard error bracketed.

Table 3. Relationship between canola seed yield and barley density, and comparisons of the regression lines.

		Regression coefficients[†]			
Year	Cultivar	*a*	*b*	*c*	R^2
1984	Tobin	210.79	-1.13 (0.29)[§]	$3.31\text{x}10^{-3}$ ($2.30\text{x}10^{-3}$)	0.82
	Westar	214.05	-0.87 (0.11)		0.72
1985	Tobin	205.41	-1.30 (0.25)	$3.24\text{x}10^{-3}$($1.38\text{x}10^{-3}$)	0.82
	Westar	172.15	-0.89 (0.10)		0.69
Combined	Tobin	206.75	-1.08 (0.18)	2.08x10-3 ($1.09\text{x}10^{-3}$)	0.74
	Westar	197.06	-0.95 (0.09)		0.63

The cultivar responses differ. Within each cultivar, the regression lines are parallel, but the intercepts differ ($P \leq 0.05$).

[†] Following the models, $Y = a + bX$ or $Y = a + bX + cX^2$ where Y is the canola seed yield (g/m^2) and X is the barley emergence count ($\#/m^2$), n=32.

[§] Standard error bracketed.

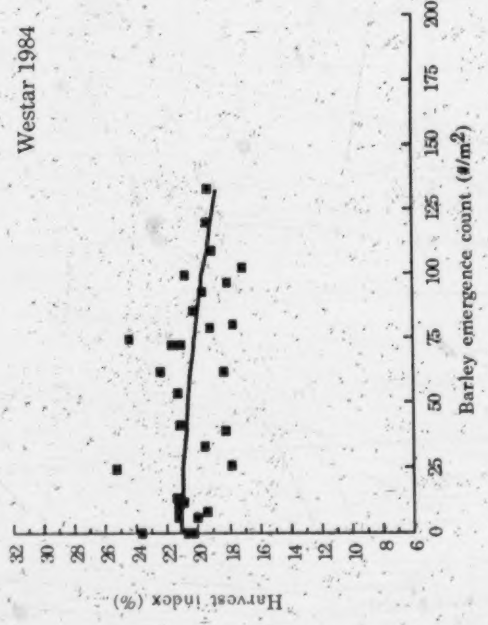
Figure 3. Relationship between harvest index and barley emergence count for canola grown with different densities of barley in 1984 and 1985.

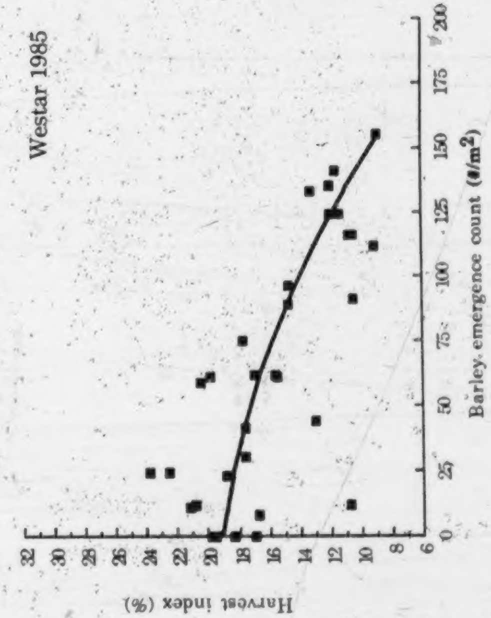
		Regression coefficients[†]			
Year	Cultivar	*a*	*b*	*c*	R^2
1984	Tobin	22.68	$1.06\text{x}10^{-2}$ ($8.06\text{x}10^{-3}$)[§]		0.26
	Westar	21.03	$-3.32\text{x}10^{-3}$ ($3.59\text{x}10^{-2}$)	$-1.12\text{x}10^{-4}$ ($3.07\text{x}10^{-4}$)	0.13
1985	Tobin	27.84	$1.79\text{x}10^{-2}$ ($5.74\text{x}10^{-3}$)		0.56
	Westar	19.02	$-2.29\text{x}10^{-2}$ ($3.19\text{x}10^{-2}$)	$-2.87\text{x}10^{-4}$ ($2.20\text{x}10^{-4}$)	0.57
Combined	Tobin	24.87	7.74x10-3 (7.58x10-3		0.31
	Westar	lines differed			

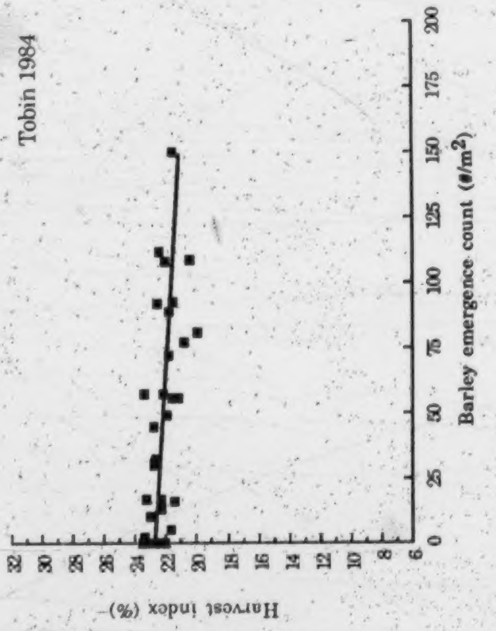
The cultivar responses differ. The Tobin intercepts differ ($P \leq 0.05$) but the regression lines are parallel. The Westar intercepts and lines differ ($P \leq 0.05$).

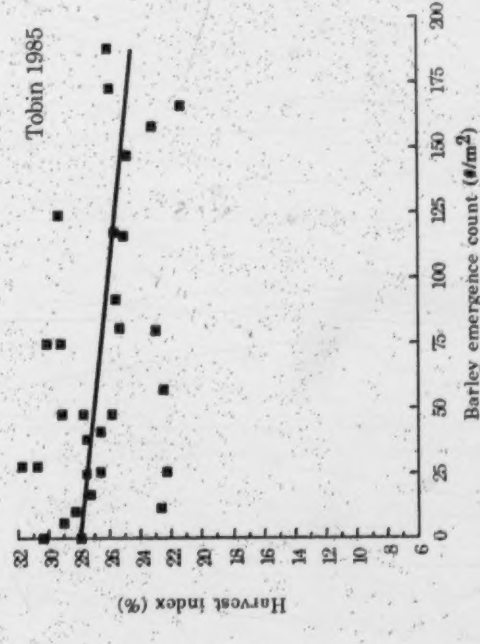
[†] Following the models, $Y = a + bX$ or $Y = a + bX + cX^2$ where Y is the canola harvest index (%) and X is the barley emergence count ($\#/m^2$), n=32.

[§] Standard error bracketed.


Westar 1984
Harvest index (%)
32
30
28
26
24
22
20
18
16
14
12
10
8
6
0
25
50
75
100
125
150
175
200
Barley emergence count (#/m²)


Westar 1985
Harvest index (%)
32
30
28
26
24
22
20
18
16
14
12
10
8
6
0
25
50
75
100
125
150
175
200
Barley emergence count (#/m²)


Tobin 1984
Harvest index (%)
32
30
28
26
24
22
20
18
16
14
12
10
8
6
0
25
50
75
100
125
150
175
200
Barley emergence count (#/m²)


Tobin 1985
Harvest index (%)
32
30
28
26
24
22
20
18
16
14
12
10
8
6
0
25
50
75
100
125
150
175
200
Barley emergence count (#/m²)

However, canola seed yield loss, as a percentage of weed-free yield, was similar in the two canola cultivars. At barley densities below 50 plants/m^2 there was a 0.5% yield loss for each barley plant present. At a barley density of 30 plants/m^2 the yield loss in both Westar and Tobin was approximately 15%. The yield reduction was much less than the loss reported for loss for *B. napus* cv Regent grown in Manitoba at the same barley density (31%) (Marshall *et al.*, 1989) or for Tobin or Westar grown at Scott, Saskatchewan (O'Donovan *et al.*, 1988).

Yield losses in canola due to barley were in the order of those expected for wild oat, considered to be a very competitive grassy weed (Pavlychenko and Harrington, 1934). Expected yield loss of rapeseed (*B. campestris* cv Span) at 30 wild oat plants/m^2, based on an equation developed largely from Lacombe data, would be 17.6% (Dew and Keys, 1976) compared to 15% canola yield loss predicted by this research at the same density of barley. Canola yield reduction due to wild oats at low plant densities (<10 plants/m^2) would be twice the yield loss expected with similar barley densities.

The discrepancies in canola seed yields in other competition experiments have been attributed to the effects of high temperatures and low rainfall, particularly during canola flowering and pod development (Marshall *et al.*, 1989, O'Donovan *et al.*, 1988). It is unlikely that soil moisture or temperature limited plant growth in 1984 at Lacombe, but warmer drier weather in July, 1985 may have limited Westar seed yield by limiting or delaying pod set (Appendices 2 and 3). Tobin largely escaped the effects of the weather by flowering and setting pods before the hot, dry conditions occurred in 1985 (pers. observation).

The environmental conditions occurring at the time of seed set or seed filling can be reflected in individual seed size. In 1984, barley density did not appear to affect seed weight (Figure 4). As is characteristic of the two cultivars used, Westar seeds were larger (3.65±0.13 g/1000 seeds) than those of Tobin (2.49±0.28 g/1000 seeds). In 1985, however, canola 1000-seed weight increased in proportion to barley density. The response to increasing barley density was similar in both canola cultivars even though the two *Brassica* species have different seed sizes. There was a 0.6% increase (based on predicted values) in 1000-seed weight for every 10 barley plants present in the canola crop. The fact that individual seeds were larger as plant density increased suggests a sink limitation.

Barley shoot weight, seed yield and culm count increased as barley density increased on an area basis (Figures 1, 2 and 5). These parameters were unaffected by

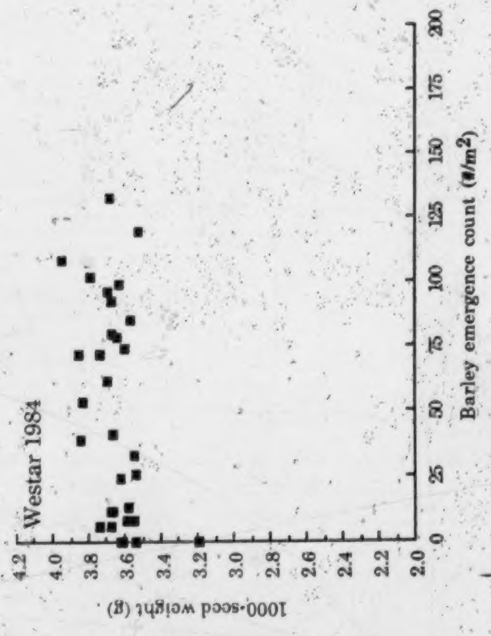
Figure 4. Relationship between 1000-seed weight and barley emergence count for canola grown with different densities of barley in 1984 and 1985.

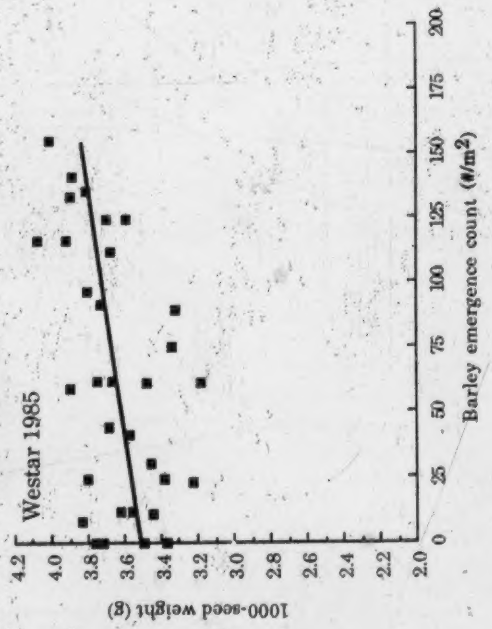
		Regression coefficients[†]		
Year	Cultivar	*a*	*b*	R^2
1984	Tobin	-	-[§]	
	Westar	-	-	
1985	Tobin	2.54	1.74×10^{-3} (7.27×10^{-4})	0.30
	Westar	3.51	2.15×10^{-3} (6.13×10^{-4})	0.22

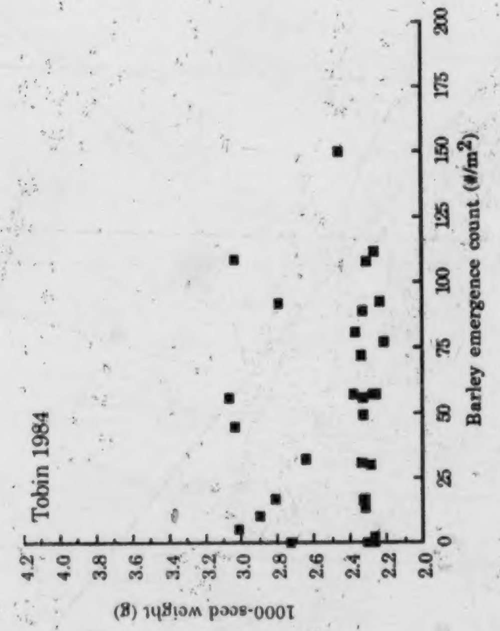
The cultivars have different intercepts but the regression lines are the same ($P \leq 0.05$).

[†] Following the model, $Y = a + bX$ where Y is the canola 1000-seed weight (g) and X is the barley emergence count (#/m^2), n=32.

[§] -, no relationship; standard error bracketed.


Westar 1984
1000-seed weight (g)
4.2
4.0
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
0
25
50
75
100
125
150
175
200
Barley emergence count (#/m2)


Westar 1985
1000-seed weight (g)
4.2
4.0
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
0
25
50
75
100
125
150
175
200
Barley emergence count (#/m2)


Tobin 1984
1000-seed weight (g)
4.2
4.0
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
0
25
50
75
100
125
150
175
200
Barley emergence count (#/m2)

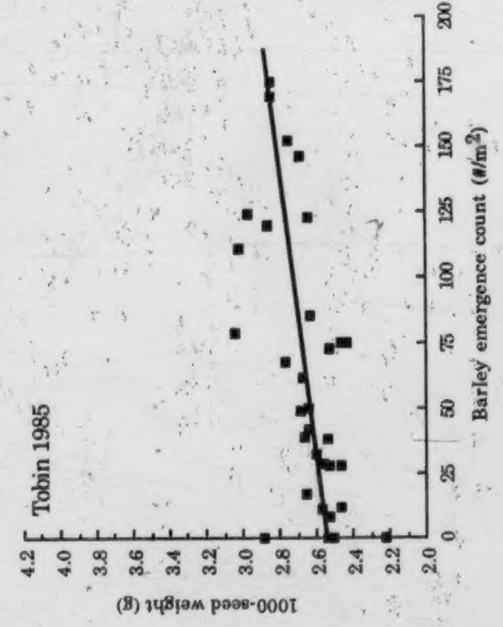

Tobin 1985
1000-seed weight (g)
4.2
4.0
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
0
25
50
75
100
125
150
175
200
Barley emergence count (#/m2)

Figure 5. Relationship between culm count and emergence count for barley grown at a range of densities with canola in 1984 and 1985.

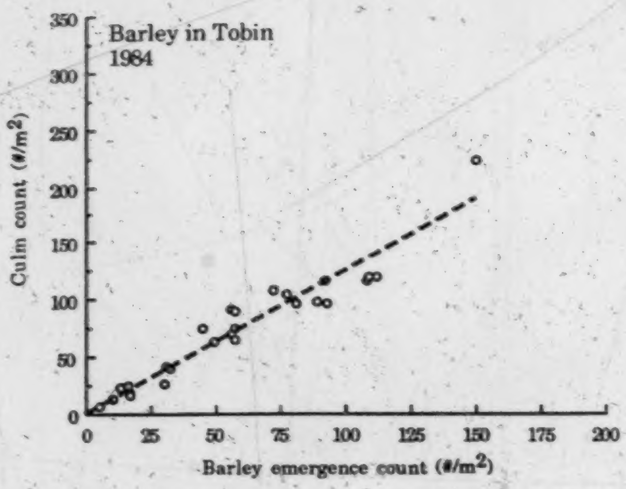
		Regression coefficients[†]			
Year	Treatment	*a*	*b*	R^2	Significance[§]
1984	Barley in Tobin	0	1.26 (0.04)[Y]	0.98	**
	Barley in Westar	0	1.47 (0.04)	0.98	**
1985	Barley in Tobin	0	1.69 (0.06)	0.97	**
	Barley in Westar	0	1.85 (0.07)	0.97	**
Combined	Barley in Tobin	0	1.54 (0.05)	0.95	**
	Barley in Westar	0	1.70 (0.05)	0.96	**
Overall	Barley in canola	0	1.61 (0.03)	0.95	**

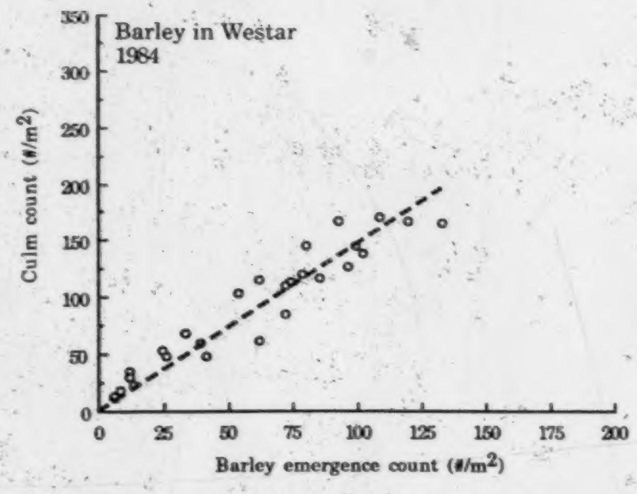
Slope (*b*) comparisons					Significance
Year	Treatment		Year	Treatment	
1984	Barley in Tobin	vs	1985	Barley in Tobin	ns
1984	Barley in Westar	vs	1985	Barley in Westar	ns
1984	Barley in Tobin	vs	1984	Barley in Westar	ns
1985	Barley in Tobin	vs	1985	Barley in Westar	ns

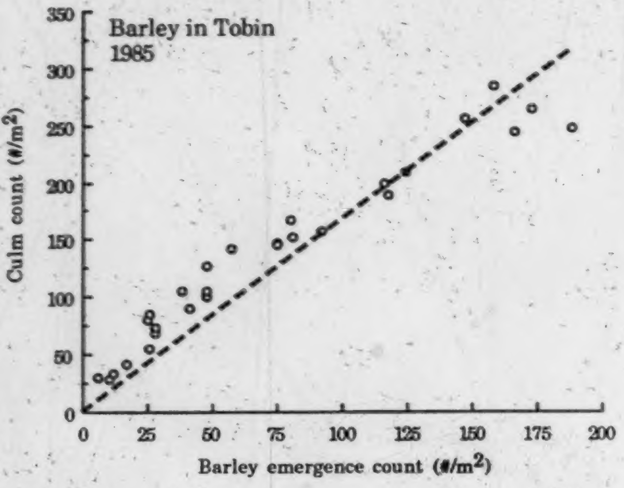
[†] Following the model, $Y=a+bX$ where Y is the barley culm count (#/m^2) and X is the barley emergence count (#/m^2), n=28.

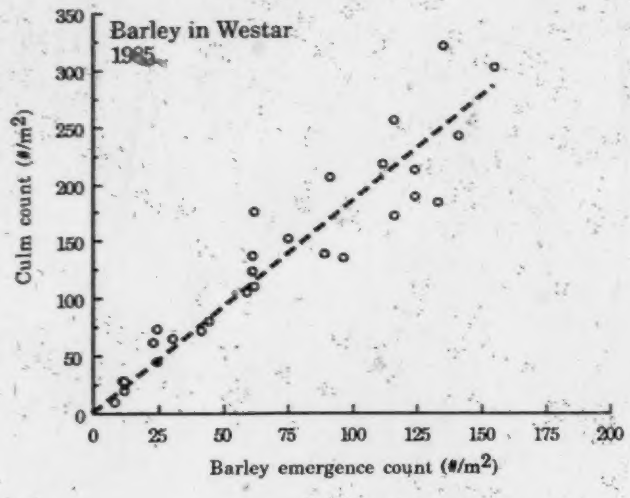
[§] ns, not significant; **, significant at $P \leq 0.01$.

[Y] Standard error bracketed.


Barley in Tobin
1984
Culm count (#/m^2)
350
300
250
200
150
100
50
0
0
25
50
75
100
125
150
175
200
Barley emergence count (#/m^2)


Barley in Westar
1984
Culm count (#/m^2)
350
300
250
200
150
100
50
0
0
25
50
75
100
125
150
175
200
Barley emergence count (#/m^2)


Barley in Tobin
1985
Culm count (#/m^2)
350
300
250
200
150
100
50
0
0
25
50
75
100
125
150
175
200
Barley emergence count (#/m^2)


Barley in Westar
1985
Culm count (#/m^2)
350
300
250
200
150
100
50
0
0
25
50
75
100
125
150
175
200
Barley emergence count (#/m^2)

the canola cultivar in which it grew (Tables 4 and 5), although data trends suggest that shoot weight, culm count and seed yield were lower when barley was grown in Tobin.

Barley grown with canola had the potential to produce higher seed yields than canola grown alone. Generally, at barley densities above 115 plants/m^2, the barley out-yielded the weed-free canola. Seed yield of both species in the mixture was optimized at 60 to 80 plants/m^2 or about 200 to 250 plants/m^2 in total. The maximum total seed yield was 250 to 280 g/m^2.

Dry matter production for canola and barley was optimized at a higher plant population than for seed yield. The contribution to the mixture by each species was 400 to 500 g/m^2. This occurred at a barley density between 110 and 160 plants/m^2 or 250 to 300 plants/m^2 in total.

The proportion of dry matter partitioned into grain varied with plant density. The data consistently suggested a quadratic relationship between barley harvest index and emergence count (Figure 6). Maximum predicted harvest index ranged from 50 to 56%. Based on calculations from the prediction equations this would occur at a barley density of approximately 100 plants/m^2.

Barley seed weight was unaffected by barley plant density in 1984 (Figure 7). However, the seed weight was slightly lower when it was grown with Westar (7.68±0.35 g) than with Tobin (8.45±0.40 g). The 250-kernel weights of the barley that had grown in Tobin were higher than those of barley grown in Westar also in 1985. This suggests that photosynthate production during the filling period was limited more by Westar than Tobin. The actual change in seed weight in response to increasing barley density in 1985 was the same for barley grown in either canola cultivar. From calculations based on the production equations, kernel weight was maximized at approximately 114 barley plants/m^2.

The intuitive observations made from shoot weight data on an area basis are substantiated by assessing the competitive abilities of Tobin, Westar and barley on a weight per plant basis. The graphs presented in Figure 8 are based on a fixed canola density of 150 plants/m^2. Individual canola plants were larger than the barley plants in 1984 and the plants became smaller as plant density increased. The situation was different in 1985 when the barley plants were bigger than the Tobin plants at all densities. Westar plants were bigger than the barley plants at the lower densities in 1985, however, they were similar in size at the highest plant densities.

Table 4. Relationship between barley seed yield and barley density, and comparisons of the regression coefficients.

		Regression coefficients[†]			
Year	Treatment	*a*	*b*	R^2	Significance[§]
1984	Barley in Tobin	0	1.68 (0.22)[Y]	0.97	**
	Barley in Westar	0	1.73 (0.15)	0.97	**
1985	Barley in Tobin	0	1.76 (0.54)	0.94	**
	Barley in Westar	0	2.04 (0.22)	0.96	**
Combined	Barley in Tobin	0	1.73 (0.06)	0.95	**
	Barley in Westar	0	1.97 (0.05)	0.96	**
Overall	Barley in canola	0	1.82 (0.04)	0.95	**

Slope (*b*) comparisons					Significance
Year	Treatment		Year	Treatment	
1984	Barley in Tobin	vs	1985	Barley in Tobin	ns
1984	Barley in Westar	vs	1985	Barley in Westar	ns
1984	Barley in Tobin	vs	1984	Barley in Westar	ns
1985	Barley in Tobin	vs	1985	Barley in Westar	ns

[†] Following the model, $Y=a+bX$ where Y is the barley seed yield (g/m^2) and X is the barley emergence count (#/m^2), n=28.

[§] ns, not significant; **, significant at $P \leq 0.01$.

[Y] Standard error bracketed.

Table 5. Relationship between barley shoot weight and barley density, and comparisons of the regression coefficients.

		Regression coefficients[†]			
Year	Treatment	*a*	*b*	R^2	Significance[§]
1984	Barley in Tobin	0	3.06 (0.10)[Y]	0.97	**
	Barley in Westar	0	3.41 (0.09)	0.98	**
1985	Barley in Tobin	0	3.58 (0.16)	0.95	**
	Barley in Westar	0	3.74 (0.15)	0.96	**
Combined	Barley in Tobin	0	3.40 (0.11)	0.95	**
	Barley in Westar	0	3.61 (0.09)	0.97	**
Overall	Barley in canola	0	3.50 (0.07)	0.96	**

Slope (*b*) comparisons					Significance
Year	Treatment		Year	Treatment	
1984	Barley in Tobin	vs	1985	Barley in Tobin	ns
1984	Barley in Westar	vs	1985	Barley in Westar	ns
1984	Barley in Tobin	vs	1984	Barley in Westar	ns
1985	Barley in Tobin	vs	1985	Barley in Westar	ns

[†] Following the model, $Y=a + bX$ where Y is the barley shoot weight (g m/^{2}) and X is the barley emergence count (# m/^{2}), n=28.

[§] ns, not significant; **, significant at $P \leq 0.01$.

[Y] Standard error bracketed.

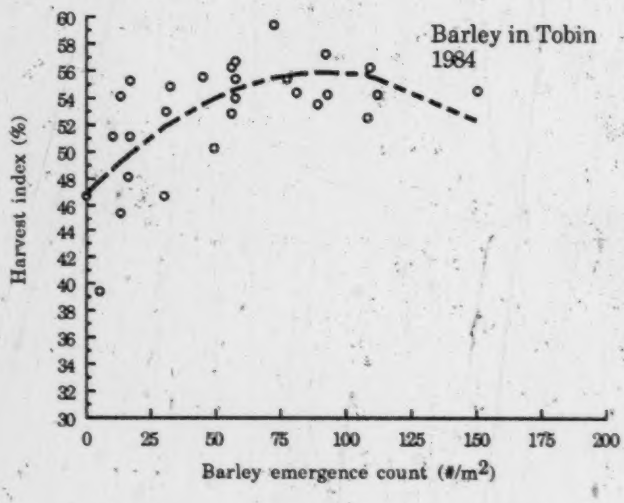
Figure 6. Relationship between harvest index and emergence count for barley grown at a range of densities with canola in 1984 and 1985.

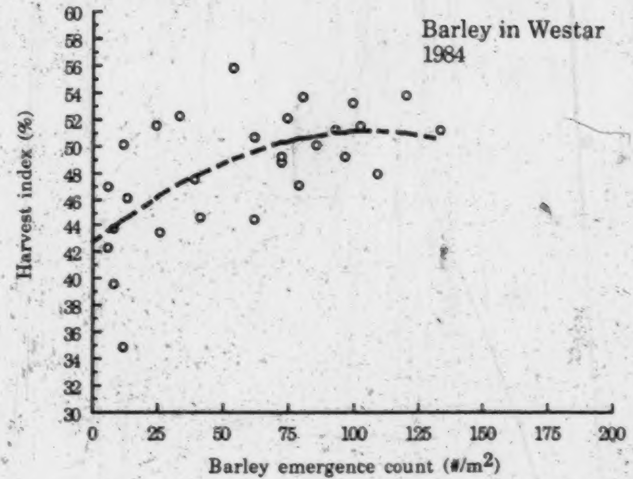
Year	Treatment	Regression coefficients[†] *a*	*b*	*c*	R^2
1984	Barley in Tobin	46.62	2.00×10^{-1} (5.11×10^{-2})[§]	-1.08×10^{-3} (3.66×10^{-4})	0.44
	Barley in Westar	42.56	1.62×10^{-1} (5.11×10^{-2})	-7.52×10^{-4} (4.60×10^{-4})	0.40
1985	Barley in Tobin	43.69	1.14×10^{-1} (5.11×10^{-2})	-4.96×10^{-4} (2.22×10^{-4})	0.33
	Barley in Westar	50.47	1.12×10^{-1} (5.11×10^{-2})	-6.31×10^{-4} (3.53×10^{-4})	0.25
Combined					
	Barley in Tobin	45.03	0.17 (0.04)	-8.52×10^{-4} (2.15×10^{-4})	0.28
	Barley in Westar	46.02	0.14 (0.05)	-6.20×10^{-4} (3.35×10^{-4})	0.25
Overall					
	Barley in canola	45.39	0.16 (0.03)	-7.96×10^{-4} (1.73×10^{-4})	0.27

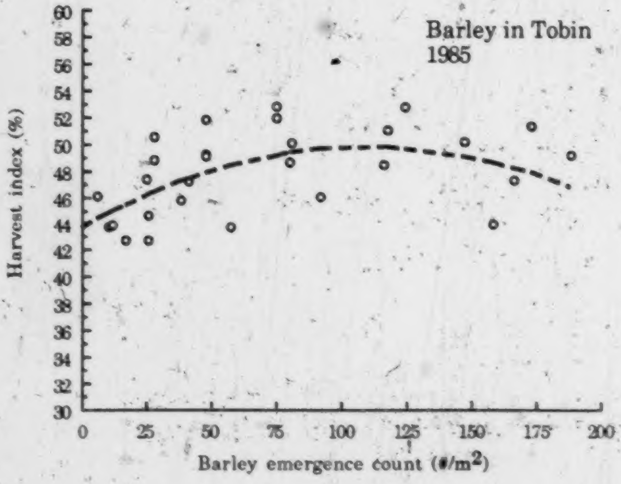
Within each cultivar, the lines are parallel, but the intercepts differ ($P \leq 0.05$).

[†] Following the model, $Y = a + bX + cX^2$ where Y is the barley harvest index (%) and X is the barley emergence count (#/m^2), n=28.

[§] Standard error bracketed.


Barley in Tobin
1984
Harvest index (%)
60
58
56
54
52
50
48
46
44
42
40
38
36
34
32
30
0
25
50
75
100
125
150
175
200
Barley emergence count (#/m2)


Barley in Westar
1984
Harvest index (%)
60
58
56
54
52
50
48
46
44
42
40
38
36
34
32
30
0
25
50
75
100
125
150
175
200
Barley emergence count (#/m2)


Barley in Tobin
1985
Harvest index (%)
60
58
56
54
52
50
48
46
44
42
40
38
36
34
32
30
0
25
50
75
100
125
150
175
200
Barley emergence count (#/m2)

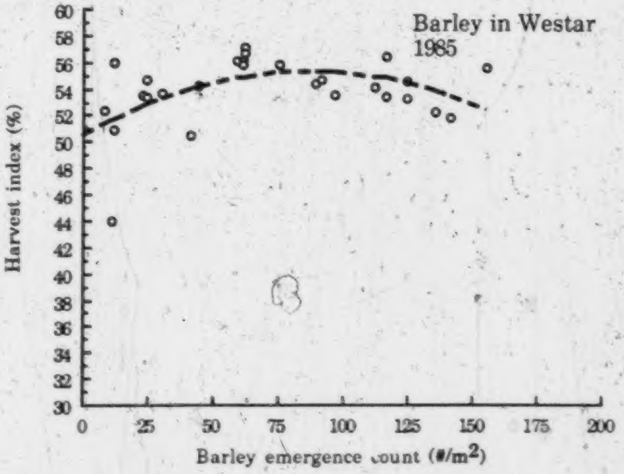

Barley in Westar
1985
Harvest index (%)
60
58
56
54
52
50
48
46
44
42
40
38
36
34
32
30
0
25
50
75
100
125
150
175
200
Barley emergence count (#/m2)

Figure 7. Relationship between 250-kernel weight and emergence count for barley grown at a range of densities with canola in 1984 and 1985.

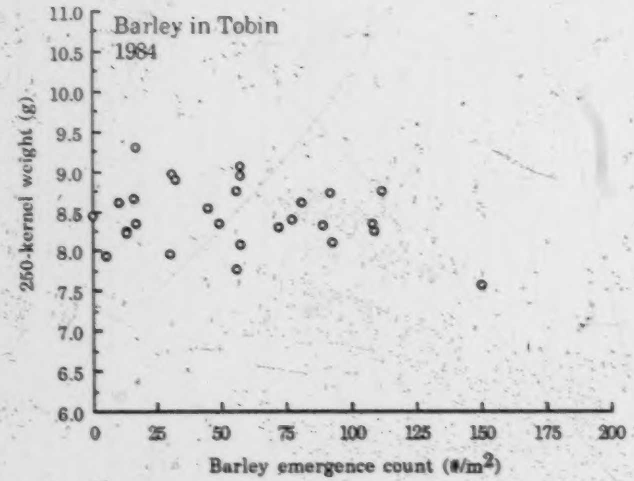
		Regression coefficients[†]			
Year	Treatment	*a*	*b*	*c*	R^2
1984	Barley in Tobin	-[§]	-	-	-
	Barley in Westar	-	-	-	-
1985	Barley in Tobin	9.05	1.87×10^{-3} (5.26×10^{-3})[¥]	-7.95×10^{-4} (2.78×10^{-5})	0.43
	Barley in Westar	7.75	2.93×10^{-2} (5.88×10^{-3})	-1.33×10^{-4} (3.75×10^{-5})	0.71

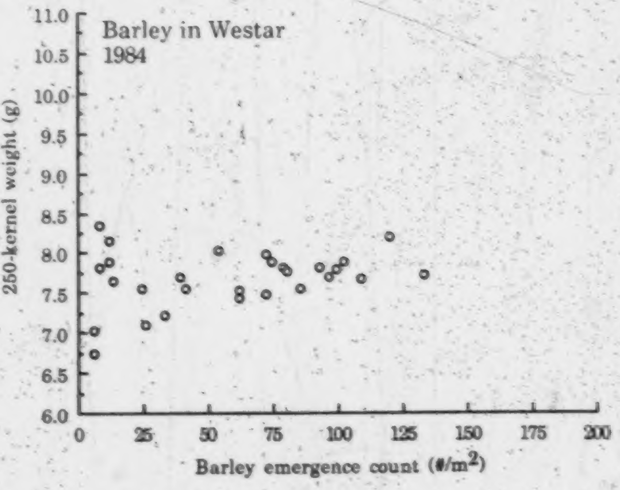
The intercepts of the two cultivars differ but the curves are the same ($P \leq 0.05$).

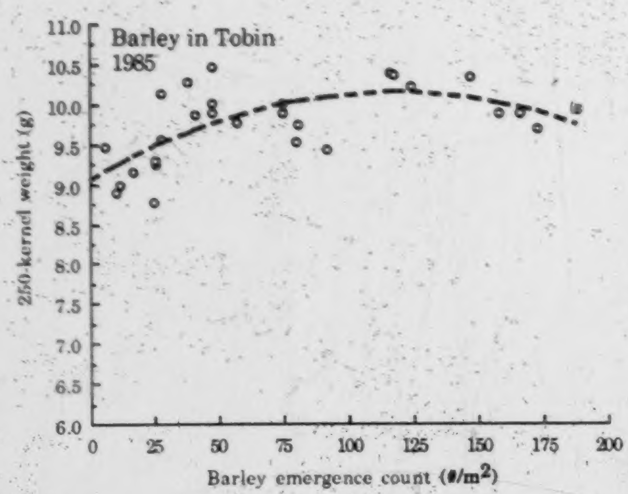
[†] Following the model, $Y = a + bX + cX^2$ where Y is the barley 250-kernel weight(g) and X is the barley emergence count (#/m^2), n=28.

[§] -, No relationship.

[¥] Standard error bracketed.


Barley in Tobin
1984
250-kernel weight (g)
11.0
10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
0
25
50
75
100
125
150
175
200
Barley emergence count (#/m^2)


Barley in Westar
1984
250-kernel weight (g)
11.0
10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
0
25
50
75
100
125
150
175
200
Barley emergence count (#/m^2)


Barley in Tobin
1985
250-kernel weight (g)
11.0
10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
0
25
50
75
100
125
150
175
200
Barley emergence count (#/m^2)

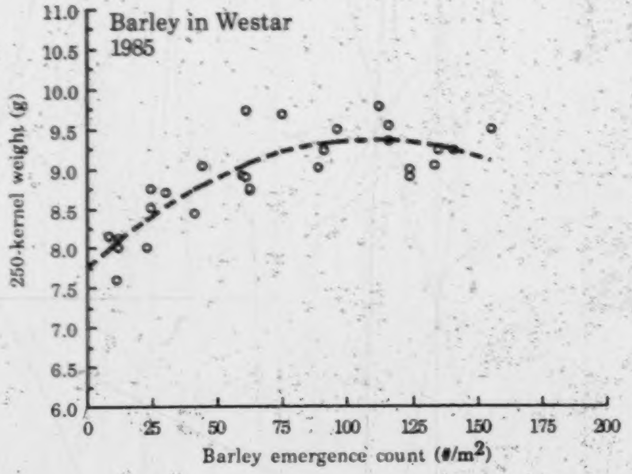

Barley in Westar
1985
250-kernel weight (g)
11.0
10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
0
25
50
75
100
125
150
175
200
Barley emergence count (#/m^2)

Figure 8. Relationship between plant emergence count and the reciprocal of plant total weight of canola and barley.

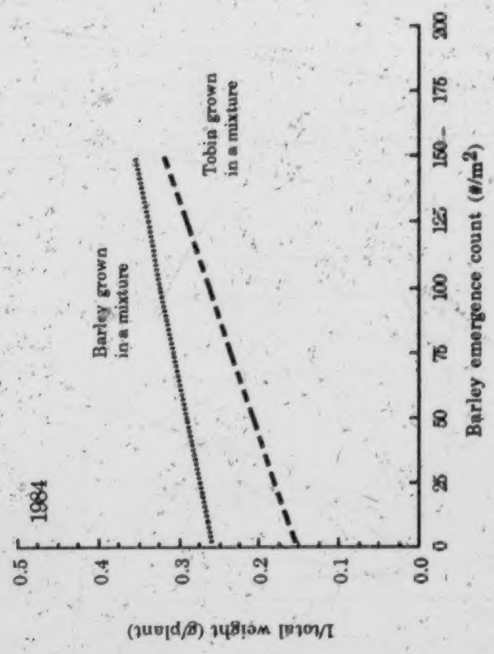
		Regression coefficients					
Year	Cultivar	*a*	*b*	*c*	*b*/*c*	R^2	Significance[†]
Canola grown with barley[§]:							
1984	Tobin	-2.80×10^{-2}	1.19×10^{-3} (1.08×10^{-4})[Y]	1.11×10^{-3} (1.00×10^{-4})	1.07	0.90	**
	Westar	-3.60×10^{-2}	1.25×10^{-3} (2.18×10^{-4})	7.55×10^{-4} (1.26×10^{-4})	1.66	0.71	**
1985	Tobin	-2.95×10^{-3}	1.35×10^{-3} (4.20×10^{-4})	1.33×10^{-3} (1.47×10^{-4})	1.02	0.78	**
	Westar	6.06×10^{-2}	6.35×10^{-4} (3.80×10^{-4})	1.04×10^{-3} (1.62×10^{-4})	0.61	0.63	**
Barley grown with canola[Ω]:							
1984	Barley in Tobin	1.76×10^{-1}	5.35×10^{-4} (3.58×10^{-4})	6.57×10^{-4} (3.33×10^{-4})	0.81	0.19	ns
	Barley in Westar	1.66×10^{-1}	3.33×10^{-4} (4.25×10^{-4})	9.18×10^{-4} (2.46×10^{-4})	2.11	0.36	*
1985	Barley in Tobin	4.86×10^{-2}	7.08×10^{-4} (3.58×10^{-4})	1.17×10^{-3} (1.25×10^{-4})	0.61	0.78	**
	Barley in Westar	1.70×10^{-2}	1.42×10^{-3} (4.88×10^{-4})	4.98×10^{-4} (2.07×10^{-4})	2.83	0.35	*

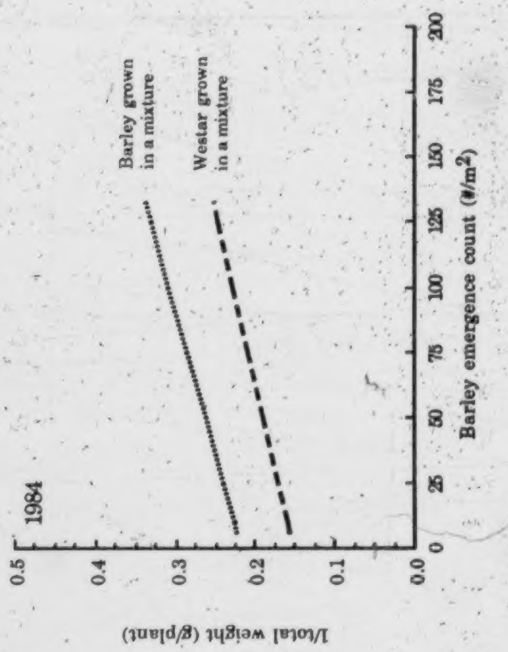
[†] ns, not significant; *, significant at $P \leq 0.05$; **, significant at $P \leq 0.01$.

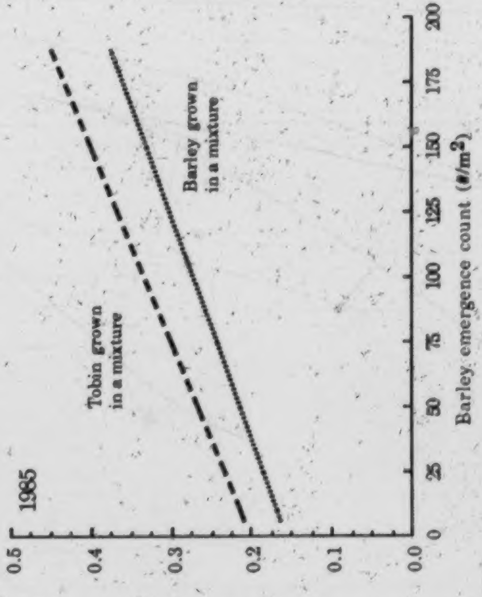
[§] Following the model, $1/Y = a + bX + cZ$ where Y is the canola total weight (g/plant) and X is the canola emergence count (#/m^2), and Z is the barley emergence count (#/m^2), n=28.

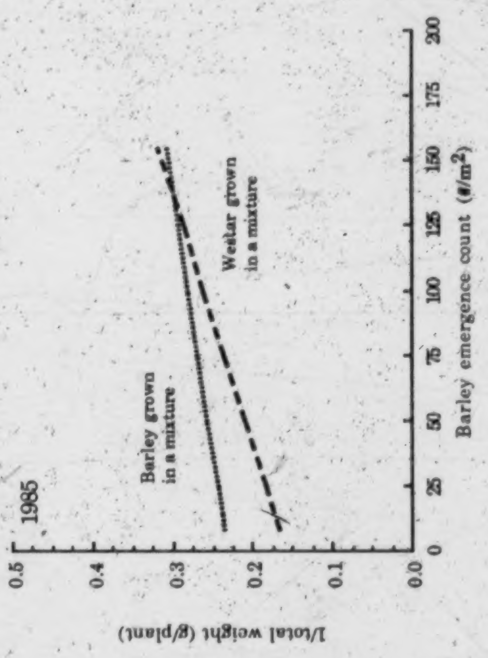
[Y] Standard error bracketed.

[Ω] Following the model, $1/Y = a + bX + cZ$ where Y is the barley total weight (g/plant) and X is the canola emergence count (#/m^2), and Z is the barley emergence count (#/m^2), n=28.


1984
Barley grown in a mixture
Tobin grown in a mixture
1/total weight (g/plant)
0.5
0.4
0.3
0.2
0.1
0.0
0
25
50
75
100
125
150
175
200
Barley emergence count (#/m^2)


1984
Barley grown in a mixture
Westar grown in a mixture
1/total weight (g/plant)
0.5
0.4
0.3
0.2
0.1
0.0
0
25
50
75
100
125
150
175
200
Barley emergence count (#/m^2)


1985
Tobin grown in a mixture
Barley grown in a mixture
1/total weight (g/plant)
0.5
0.4
0.3
0.2
0.1
0.0
0
25
50
75
100
125
150
175
200
Barley emergence count (#/m^2)


1985
Barley grown in a mixture
Westar grown in a mixture
1/total weight (g/plant)
0.5
0.4
0.3
0.2
0.1
0.0
0
25
50
75
100
125
150
175
200
Barley emergence count (#/m^2)

Based on the ratio of the regression coefficients in Figure 8, competition in both years was greater between Tobin plants than between Tobin and barley plants. For a Tobin plant, the addition of a barley plant was essentially the same as adding another Tobin plant (ratios 1.07 and 1.02). The presence of one Tobin plant to barley was less than adding another barley plant (ratios 0.81 and 0.61). The situation was reversed in Westar. Inter-specific competition between Westar and barley (2.11 and 2.83) was greater than intra-specific competition (1.66 and 0.61) in Westar.

The competitive abilities of Tobin and Westar differ in this experiment and the one described in Chapter 2 for 1985 (the year the two experiments share in common). Since the experiments were in close proximity in the field, it is unlikely that environment alone could account for the difference in competition. A more plausible reason for the discrepancy is the difference in the ratio of canola to barley in the two experiments. This explanation could be tested by performing a replacement series experiment in which different proportions of canola and barley would be grown together at a set total plant density.

Economics. The yield-density relationships between canola and barley that were developed (Table 3) were used to examine the economics of controlling barley with a post-emergence herbicide. The value of the canola crop, when barley was controlled with a herbicide, was:

A = *[Barley-free canola yield* x *Market price] - [Herbicide + Application cost]*

This model assumes that there is no yield loss prior to treatment or after herbicide treatment. The cash return (seeding, fertilizer and harvesting costs not included) on canola when barley is not controlled, and assumed to have no economic value, was:

B = *[Canola yield at various barley densities* x *Market price]*

The cash return when barley is not controlled, and considered to have economic value, was:

C =*{ [Canola yield at various barley densities* x *Market price] + [Barley yield at various densities* x *Market price] } - Separation cost*

The following assumptions were made:

(1) Barley-free Tobin seed yield=2.07 t/ha, barley-free Westar seed yield=1.97 t/ha (intercepts of the regression equations for years combined).

(2) August 28, 1989, Alberta Wheat Pool price at the Lacombe elevator; No. 1 canola, \$5.46/bu or \$240.51/t; No. 1 barley, \$1.77/bu or \$81.22/t.

(3) Barley control with the recommended rate of POAST™[7] (sethoxydim[8], 266 g ai/ha) plus ASSIST OIL CONCENTRATE and ammonium sulphate. Lacombe Fertilizer price, August 28, 1989, $47.20/ha.

(4) Herbicide application cost, $6.75/ha. This was the average custom application cost for Region 5 in 1988[9].

(5) The maximum seed separation cost for canola and barley, Bentley Seed Cleaning Co-operative, August 28, 1989, $9.95/t.

The cash value of the two *Brassica* species differed because the yield potential of the two cultivars differed at Lacombe. The consequence was that averaged over 1984 and 1985, weed-free Tobin canola returned $443/ha while Westar returned only $420/ha (at the assumed prices).

If the barley is considered as a weed with no economic value, herbicide spraying could be justified at 21 plants/m^2 in Tobin and 24 plants/m^2 in Westar (the points where lines A and B intersect, Figure 9). There was little difference between the two canola cultivars under these circumstances.

The economic thresholds differ between Tobin and Westar canola when the value of the barley grain is considered. Post-emergence herbicide treatment could be rationalized at 57 barley plants/m^2 in Tobin but not before there were 79 barley plants/m^2 in Westar (intersection of lines A and C, Figure 8). Volunteer barley densities in this range could occur in fields where barley harvest was delayed and shattering occurred or if a combine was not adjusted correctly in the year prior to seeding canola. The threshold densities observed in this experiment are far above the average values (approximately 5/m^2) recorded for volunteer barley in canola on the prairies (Thomas, 1978; Thomas, 1979; Pickle, 1989).

There are a number of factors that will affect the economic thresholds presented. If the herbicide cost were reduced, or if the product was required to control other weeds such as wild oats or green foxtail, the economic threshold would be reduced. When the crop is unlikely to make No. 1 grade, *e.g.* Westar grown under marginal environmental conditions at Lacombe, or if the cash price for the crop is low, the weed threshold would increase. When cash prices are high or the yield potential is

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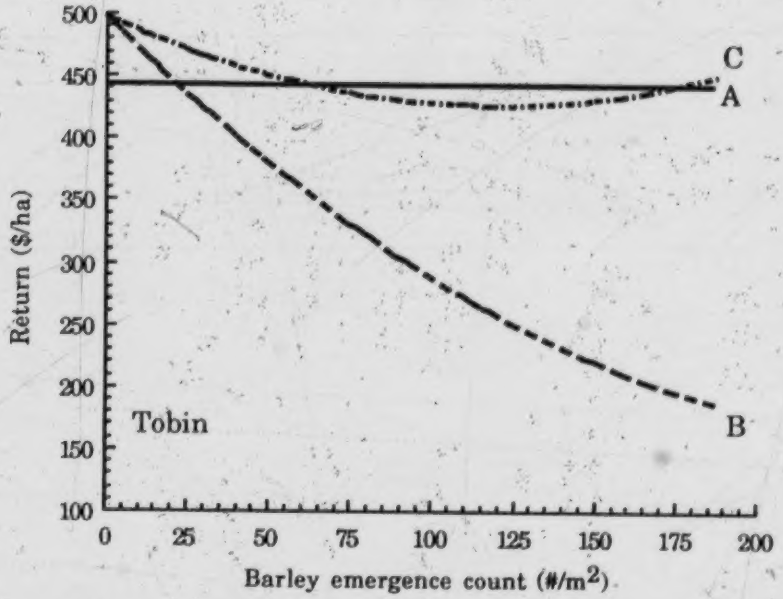
[7] BASF Canada Inc., 1700-521 3 Ave., S.W., Calgary, Alberta T2P 3T3

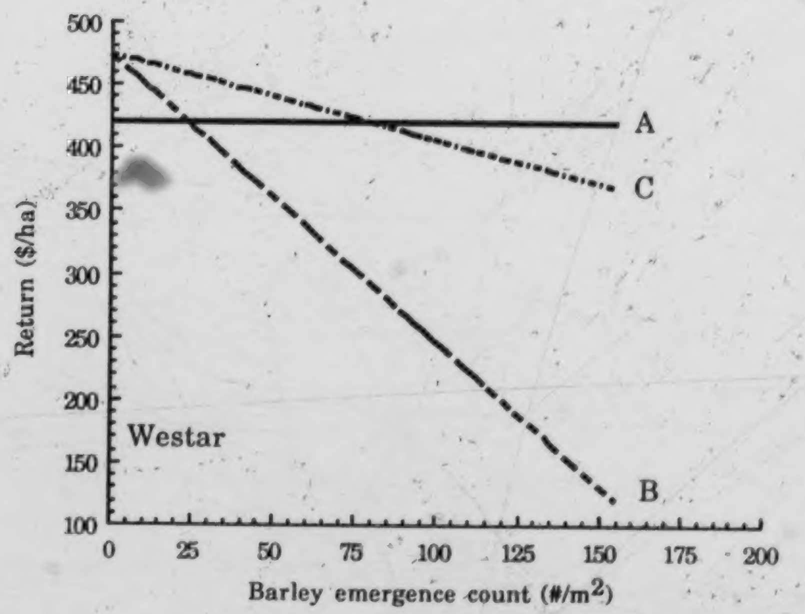
[8] 2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one

[9] Custom Rates Survey Summary 1989. Agdex No. 825-9. Alberta Agriculture.

Figure 9. Economics of barley control in canola.

Line A is the cash return on weed-free canola. Line B is the cash return when barley is not controlled. Line C is the cash return when barley is not controlled but considered to have an economic value.


Return ($/ha)
500
450
400
350
300
250
200
150
100
0
25
50
75
100
125
150
175
200
Barley emergence count (#/m2)
Tobin
A
B
C

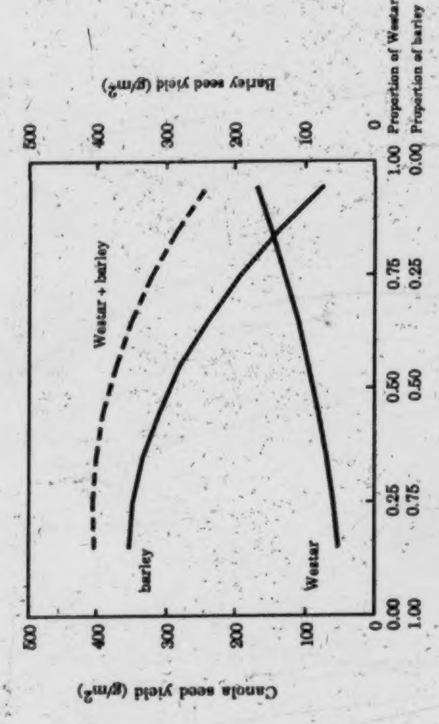

Return ($/ha)
500
450
400
350
300
250
200
150
100
0
25
50
75
100
125
150
175
200
Barley emergence count (#/m2)
Westar
A
B
C

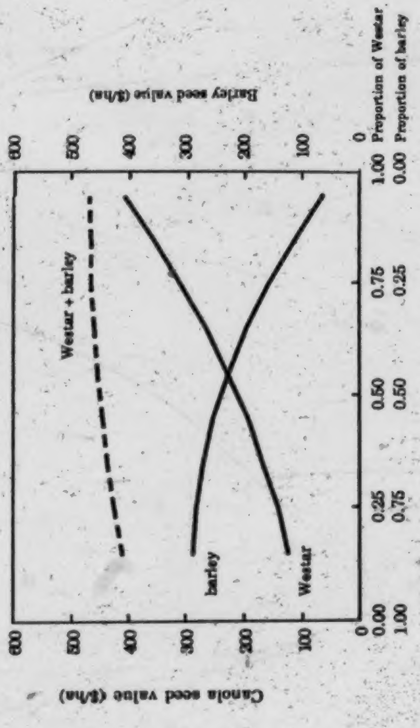
large, *e.g.* Tobin canola grown at Lacombe, spraying of volunteer barley could be justified at much lower barley densities. Another consideration is whether the barley will mature at the same time as the canola crop. Late emerging or late maturing barley may produce little useable grain while creating combining and storage problems. When the cash price for canola, herbicide and application cost and barley value are considered, it is difficult to justify post-emergence spraying for barley control at the present time.

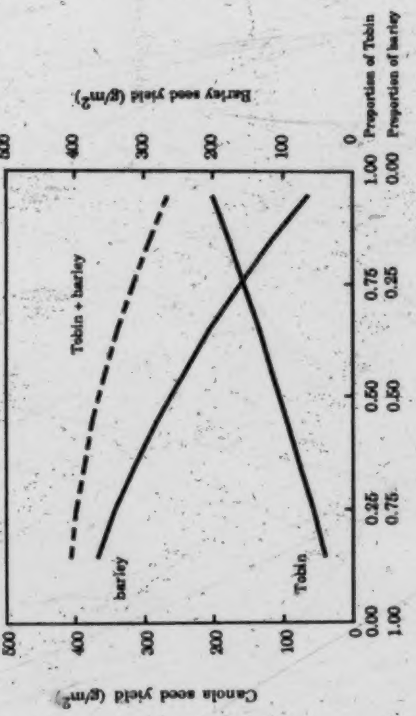
Combining the 1985 data from Chapters 2 and 3 emphasizes the difference in the relationship between seed yield in canola/barley mixtures and the potential cash return in canola/barley mixtures (Figure 10). Tobin and Westar do not have the yield potential of barley. This is to be expected as more energy is required to produce a gram of canola, compared to barley, because it is an oilseed crop. The density at which canola and barley contributed equally to the mixture different for the two canola cultivars. Canola and barley contributed equally to seed yield when 75% of the plants were Tobin or 90% of the plants were Westar. Tobin reduced barley seed production to a greater extent than Westar. This was particularly evident when Tobin constituted 25 to 75% of the plants in the mixture. Conversely, when seed yield of Westar and barley was combined in this proportion range (.25 to .75), total seed yield is greater for Westar than Tobin.

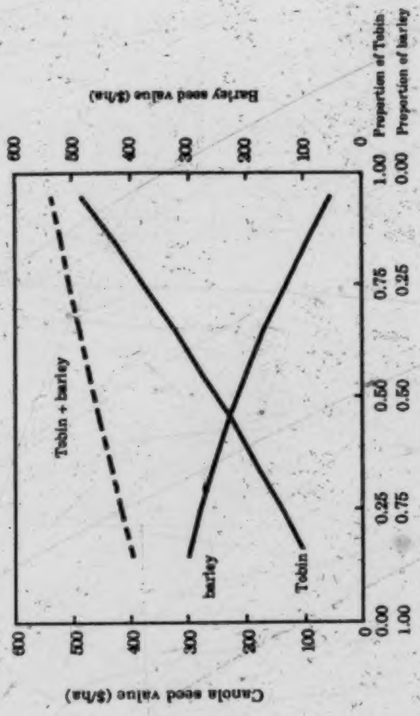
A higher total seed yield did not translate into a greater dollar value for the mixture. This is because the value of canola was three times that of barley. The potential dollar return was greater for the Tobin/barley mixture (Figure 10). This was because Tobin was able to produce more seed than Westar in most of the mixture proportions. Unlike the seed yield situation, the cash value of both Tobin and Westar equalled barley when canola was 45 to 55% to the mixture.

Figure 10. Relationship between seed yield and seed value when canola and barley are grown at different densities in mixtures.


Canola seed yield (g/m²)
Barley seed yield (g/m²)
Proportion of Westar
Proportion of barley
0
100
200
300
400
500
0.00
0.25
0.50
0.75
1.00
1.00
0.75
0.50
0.25
0.00
Westar + barley
barley
Westar


Canola seed value ($/ha)
Barley seed value ($/ha)
Proportion of Westar
Proportion of barley
0
100
200
300
400
500
600
0.00
0.25
0.50
0.75
1.00
1.00
0.75
0.50
0.25
0.00
Westar + barley
barley
Westar


Canola seed yield (g/m²)
Barley seed yield (g/m²)
Proportion of Tobin
Proportion of barley
0
100
200
300
400
500
0.00
0.25
0.50
0.75
1.00
1.00
0.75
0.50
0.25
0.00
Tobin + barley
barley
Tobin


Canola seed value ($/ha)
Barley seed value ($/ha)
Proportion of Tobin
Proportion of barley
0
100
200
300
400
500
600
0.00
0.25
0.50
0.75
1.00
1.00
0.75
0.50
0.25
0.00
Tobin + barley
barley
Tobin

SUMMARY

Canola seed yield declined as barley density increased. On a g/m^2 basis, Westar (*B. napus*) seed yield was reduced by the presence of barley more than Tobin (*B. campestris*) seed yield. When yield loss was calculated on a percentage basis, the decline in seed yield per barley plant was similar in the two canola cultivars.

Canola and barley reacted to the increased barley population in different ways. Increasing barley density resulted in less canola dry matter production on an area basis. This was accomplished by producing smaller individual canola plants rather than reducing the overall number of plants present. Seed yield was not maintained as a constant proportion of dry weight. Yield loss due to increasing densities of barley was accelerated by the fact that harvest index as well as shoot weight declined as barley density increased. Although fewer seeds were produced at high plant densities, they were larger than canola seeds produced by plants at lower densities.

Barley shoot weight and seed yield increased as the barley plant population increased. However, at the highest populations, grain yield/unit area actually declined as a proportion of whole plant dry weight. Maximum harvest indices and seed weights (1985) occurred around 100 plants/m^2 (or a total plant population of 240 plants/m^2). As canola density was constant, this suggests that intra-crop competition between barley plants began to limit barley seed yield at barley densities over 100 plants/m^2.

Under current market conditions, post-emergence spraying of volunteer barley in canola could not be rationalized. The economic threshold of 57 barley plants/m^2 in Tobin and 79 barley plants/m^2 in Westar exceeded the barley densities that a producer would experience under normal production conditions. The difference in the two threshold values calculated for Westar and Tobin was due to the disparity in the yield potential of the two canola cultivars under Lacombe conditions.

The notion that *B. napus* might be more competitive because the plants are larger (higher dry weight, taller) and have more leaf area was not supported by these results. It was clear that selection of the best adapted variety is always wisest under short-season conditions.

CHAPTER 4

COMPETITION BETWEEN CANOLA AND BARLEY EMERGING AT DIFFERENT TIME INTERVALS RELATIVE TO THE CROP: EFFECTS ON THE CANOLA CROP AND BARLEY

INTRODUCTION

The time at which a weed emerges into a crop stand influences the growth and seed yield of both crop and weed. A number of reports in the literature have described the interaction between the time of emergence of a grassy weed (most often wild oats, *Avena fatua* L.) in a gramineous crop. McBeath *et al.* (1970), for example, reported that seeding wild oats eight days before barley significantly decreased barley dry matter and culm production in a growth cabinet experiment. Unfortunately, these results were not well supported by field results. In field experiments by O'Donovan *et al.* (1985), barley and wheat yields were reduced by approximately three percent for each day that wild oats emerged before the crop. Both wild oat density and crop density were important factors in determining the yield reduction.

To the author's knowledge, Williams (1964) is the only researcher who has examined the effect of the time of emergence of a weed in a *Brassica* crop. Kale (*Brassica oleracea* L.) and lamb's-quarters (*Chenopodium album* L.) were grown at 400 and 100 plants/m^2 and seeded 14 days before, at the same time, or 14 days after each other. Kale reacted to high density by increased mortality while lamb's-quarters exhibited plasticity of plant growth. Dry weight of the kale was reduced by lamb's-quarters emerging 14 days before or at the same time as the crop. When lamb's-quarters emerged 14 days after the crop, the kale weight was similar to the dry matter produced by weed-free kale. Leaf area of both kale and lamb's-quarters was lower in the mixtures than in pure stands. Lamb's-quarters exhibited internode elongation when it emerged after the crop, which allowed it to avoid shading. The success of the weed was attributed to this feature of its development. Kale showed little internode elongation, even if it emerged 14 days after the lamb's-quarters. The advantages gained by early emergence were maintained by the species that emerged first and increased over time.

The first objective of this experiment was to determine how the time of barley emergence in canola affected the development of the canola and the barley. Any effect of time of barley emergence on canola growth and yield will be superimposed on the basic sequential developmental pattern of the crop and will be reflected in final seed yield. Three canola developmental phases have been identified based on the sources of photosynthate used for growth. Initially, the leaves provide photosynthate for root and further leaf development. Eventually, the stem becomes a net exporter of photosynthate and this material is critical to flower and early pod development. Finally, photosynthate from the pod walls fills the canola seeds (Major *et al.*,1984). There are three phases during barley development that may be sensitive to environmental stresses that affect final seed yield. They are tiller and spike initiation that occurs prior to stem elongation; dry matter production during stem elongation which can affect seed set and seed filling; and fertilization, grain growth and maturation (Wych *et al.*, 1985).

The second objective of this experiment was to quantify the relationship between time of barley emergence and seed yield, and to identify the components of seed yield that were critical to attaining that yield.

The third objective was to determine the cost-effectiveness of controlling barley that emerges at different times in a canola crop.

MATERIALS and METHODS

Field procedure. Field experiments were conducted at the Agriculture Canada Research Station, Lacombe, Alberta (52° 28' latitude, 113° 44' longitude) in 1985 and 1986. The plots were established on weed-free, fallowed Ponoka silt loam soil (26% sand, 34% silt, 40% clay, OM 9% pH 6.0). The seedbed was prepared by cultivating two or three times in the spring with a vibrashank cultivator, followed by harrowing with a spike-tooth harrow.

Brassica campestris cv Tobin and *B. napus* cv Westar canola-type rapeseed were seeded as the crop and *Hordeum vulgare* cv Galt was used to simulate volunteer barley. The experiment was set out in a split-block design. Individual plots were 2.7 by 3.7 m. Percent seed germination and estimated seed vigour were factored into the seed rates for the canola and barley. Barley was seeded at a target density of 75 plants/m^2. The time of emergence treatments were arranged in a randomized design, constituting the main effects or whole plots. The barley was seeded to emerge 6, 4 or 2 days before the canola crop, at the same time as the canola crop (0), and 2, 5 or 6 days after the canola crop. A weed-free canola check treatment was also included in the experiment. In the sub-plot treatments, Tobin or Westar canola was seeded at a target density of 200 plants/m^2 in strips that were randomized across four replications. The canola and barley were planted with a double-disk press-type drill in 23-cm rows. The canola seed was dressed with VITAVAX RS FLOWABLE™[1] (carbathiin[2] 1 g ai/kg seed; thiram[3] 2 g ai/kg seed; lindane[4] 15 g ai/kg seed) for flea beetle (*Phyllotreta cruciferae* Goeze, *P. striolata* Fab.) and fungal seedling disease protection prior to planting. In both years, 63 kg/ha monoammonium phosphate (11-51-0) fertilizer was applied with the canola seed.

After plant emergence, a 0.84 m^2 area was selected and marked in each plot. The following data were recorded in each quadrat: canola plant counts at emergence and harvest, barley plant counts at emergence, canola shoot dry weights, seed yield, and 1000-seed weights at harvest. Harvest indices[5] were calculated. The seeding, emergence and final harvest dates are listed in Table 1.

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[1] Uniroyal Chemical Ltd., 4-2216 27 Ave. N.E., Calgary, Alberta T2E 7A7

[2] gamma-1,2,3,4,5,6-hexachlorocyclohexane

[3] bis(dimethylthiocarbamoyl)disulfide

[4] 5,6-dihydro-2-methyl-1,4-oxathiin-3-carboxanilide

When mature, the canola plants were hand-cut approximately 5 cm above ground level and placed in large cotton bags. The samples were dried to constant weight before threshing in a stationary thresher.

At final harvest, five-plant canola subsamples were randomly selected from plants adjacent to the quadrat and harvested with the root intact. Plant heights and pod-bearing branch counts (primary, secondary, tertiary and quarternary) were recorded and the plants were individually wrapped in newspaper, and put in a paper bag inside a large cotton sack to dry at 55 C. After drying, the root of each canola plant was removed from the shoot. The shoot was weighed before the pods were removed and counted. For a pod to be included in the pod count it had to have at least one developed seed. The pods containing seeds were weighed, and the seed was harvested by hand threshing. The individual seeds were counted using an electronic seed counter[6] and then weighed. The total number of branches, seeds per pod and 1000-seed weights for the individual plants were calculated from the preceding information.

Four harvests were made during the growing season in 1985. At each harvest, a 0.21 m^2 area was randomly selected in the plot and all the plants in the quadrat were removed using a spade. The soil adhering to the roots was washed off and the numbers of canola and barley plants were recorded. Five canola and five barley plants were selected as a subsample for each plot. The rest of the plants were separated into shoots and roots, placed in paper bags and oven dried at 80 C to a constant weight. Plant heights were recorded on each of the five subsample canola plants which were then separated into roots, green leaves and bracts, senesced leaves, stems, flowers and buds, and pods. Barley plant height and number of tillers were recorded on the subsample plants and they were divided into roots, green leaves, senesced leaves, stems and heads. Non-senescent leaf area of the canola and barley plants was determined using a LI-3000 Portable Area Meter™[7] immediately after the leaves were removed. Canola pods and stems were also passed through the area meter to provide a rough estimate of

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[5] Harvest index (%) = $\frac{\text{seed yield}}{\text{seed+stem weight}} \times 100$

[6] Electronic seed counter, Model 850-2, The Old Mill Company, Savage Industrial Center, Savage, Maryland, USA 20763

[7] LI-COR Inc., Box 4425, Lincoln, Nebraska, USA 68504

Table 1. Dates of seeding, emergence and harvest.

Year	Crop or weed	Seeding date	Emergence date	Harvest date
1985	Tobin	May 22	May 30	Aug. 23
	Westar	May 21	May 30	Sept. 18
	Barley in crop	May 15	May 21	with crop
	Barley in crop	May 17	May 23	with crop
	Barley in crop	May 19	May 25	with crop
	Barley in crop	May 21	May 30	with crop
	Barley in crop	May 23	June 2	with crop
	Barley in crop	May 27	June 4	with crop
	Barley in crop	May 29	June 7	with crop
1986	Tobin	May 27	June 1	Sept. 8
	Westar	May 27	June 1	Sept. 17
	Barley in crop	May 20	May 27	with crop
	Barley in crop	May 23	May 29	with crop
	Barley in crop	May 25	May 30	with crop
	Barley in crop	May 27	June 1	with crop
	Barley in crop	May 29	June 3	with crop
	Barley in crop	May 31	June 5	with crop
	Barley in crop	June 2	June 8	with crop

area. The areas were taken on samples from two of the four replications and the relationship between area and dry weight was used to calculate the areas from the dry weights of each component for the other two replications. The exception was the first sampling date when the areas were obtained ~~on~~ plants in all four replications. Leaf area indices (LAI's[8]) were determined. The plant components were oven-dried at 80 C to a constant weight.

Growth stage observations were made on both the canola and barley in 1986. Phenological observations (made on 10 plants) were made weekly during June and July based on Berkenkamp's (1973) scale for canola and Zadoks' scale (Zadoks *et al.*, 1974) for cereals. One mid-season harvest was made in 1986 following the procedure used in 1985.

Data analysis. Analysis of variance was used, after the data was tested for homoscedasticity, to interpret the effects of time of barley emergence on canola and barley development at each harvest date. Analysis of variance was also applied to data from 1986. Correlation was used to examine the relationship between final canola seed yield and canola total weight, and leaf, stem and pod area collected during the growing season. Correlation was also used to investigate the association between barley seed yield and total weight and leaf area.

The relationship between the relative time of barley emergence and canola shoot weight, seed yield, harvest index and 1000-seed weight at final harvest was examined using stepwise regression. Parameters entered into the equations included days, days squared, barley emergence count and crop emergence count. A negative value for days denoted barley emerging before the crop; zero, barley and canola emerged simultaneously; positive values represented barley emerging after the crop.

Linear correlation was used to measure the association between canola seed yield on an area basis and canola seed yield on a per plant basis at harvest time. Regression analysis was used to describe the relationship between the time of barley emergence relative to the crop and the components of canola yield (branches, pods, seeds per pod and 1000-seed weight). The data (mean of the five-plant subsamples) were fitted with either a linear or quadratic equation. A $\log_{10}(x+1)$ transformation was required to normalize data for seed yield per plant and pods per plant.

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[8] Leaf area index (%) = $\frac{\text{green leaf area}}{\text{ground area}}$

Stepwise linear multiple regression was used to identify the most important parameters contributing to canola seed yield on a per plant basis.

RESULTS and DISCUSSION

Plant Development. Total dry matter production by the canola plants was reduced by the presence of barley. The reduced canola dry weights were evident at canola harvests during the season and were carried through to final harvest (Table 2). An exception occurred at 32 days after seeding. It is likely that little competition between the barley and canola had occurred by this time.

The reduction in canola dry matter production observed during the growing season was essentially the same, whether the barley emerged nine days before or eight days after canola. There were, however, trends in the data which suggested that canola dry matter production was less as barley emerged earlier in relation to the crop. This trend was apparent in the 64-day harvest in both years and was carried through to final harvest (Tables 2 and 3).

The reduction in canola total weight due to barley was not a result of fewer plants being present (increased plant mortality) but of the smaller size of individual plants. No reduction in plant stand was observed in 1985. The canola plant stand averaged 112 ±3 plants/m^2 in this year. In 1986, canola plant counts at harvest were 24% less than emergence counts. This reduction was the same for all barley density treatments.

Canola dry matter production was not spread evenly throughout the growing season. Most of the plant dry weight was added after anthesis. Approximately 27% of the final harvest shoot dry weight was present at flowering in both weedy and weed-free canola. Although most canola biomass is produced after flowering, the pre-anthesis phase of canola growth is critical to final seed yield (Evans, 1984). The leaf and stem material produced at this time are part of a growth "chain reaction". Each provides a basis for further growth, and the ultimate size of each component is reflected in the size of the one that follows (Adams, 1967).

Total dry matter production, under weed-free conditions, has been found to be a major determinant of final seed yield (Campbell and Kondra 1978a; Thurling 1974a). One could anticipate a yield reduction due to barley as early as 32 days after seeding (in 1985) when barley emerging eight days after the crop lowered plant weight by 39%.

One plant strategy to enhance survival when dry matter production is limited due to weeds could be to alter the weight of various plant parts. For instance, canola that

Table 2. The proportion of dry matter in canola component parts, leaf area indices, plant heights at four harvests and final harvest during 1985.

Harvest/ parameter	Time of barley emergence relative to the canola crop								Cultivar	
	-9 days	-7 days	-5 days	0 days	3 days	5 days	8 days	Weed-free	Tobin	Westar
Canola harvested 32 days after seeding										
Total weight (g/m^2)	27.8 a[†]	23.4 ab	25.7 a	23.7 ab	20.7 ab	13.5 b	17.5 ab	28.9 a	19.7 a	25.8 a
% Leaves[§]	82.9 a	85.2 a	85.7 a	86.7 a	84.1 a	86.7 a	85.5 a	85.8 a	86.9 a	83.8 a
% Stem	9.2 a	7.0 ab	6.1 ab	4.9 b	7.2 ab	5.3 b	6.5 ab	6.2 ab	6.1 a	7.0 a
% Root	7.9 a	7.8 a	8.2 a	8.4 a	8.7 a	8.0 a	8.0 a	8.0 a	7.0 b	9.2 a
LAI[¥] (m^2/m^2)	0.55 a	0.43 ab	0.53 a	0.53 a	0.40 ab	0.24 b	0.32 ab	0.51 a	0.38 a	0.50 a
Stem area (m^2/m^2)	0.008 a	0.006 ab	0.007 ab	0.006 ab	0.006 ab	0.003 b	0.004 b	0.006 ab	0.006 a	0.006 a
Plant height (cm)	9 a	10 a	9 a	9 a	9 a	8 a	8 a	9 a	8 b	10 a
Canola harvested 50 days after seeding										
Total weight (g/m^2)	155 b	166 b	168 b	143 b	168 b	171 b	130 b	251 a	188 a	151 b
% Leaves	42.9 a	41.8 a	43.4 a	44.1 a	44.3 a	45.6 a	45.5 a	44.5 a	35.5 b	52.2 a
% Stem	37.0 ab	37.9 a	36.3 ab	35.6 ab	35.1 ab	34.4 ab	33.0 b	34.9 ab	39.3 a	32.0 b
% Flowers and Pods	7.8 a	8.5 a	8.2 a	8.3 a	7.7 a	7.8 a	8.7 a	8.0 a	13.4 a	3.0 b
% Root	12.4 a	11.8 a	12.1 a	12.0 a	12.8 a	12.2 a	12.8 a	12.5 a	11.8 a	12.8 a
LAI (m^2/m^2)	1.67 bc	1.46 bc	1.71 bc	1.58 bc	1.58 bc	1.87 b	1.19 c	2.62 a	1.45 b	1.96 a
Stem area(m^2/m^2)	2.07 b	1.80 b	1.71 b	1.65 b	1.78 b	1.81 b	1.11 c	2.72 a	2.24 a	1.45 b
Plant height (cm)	47 a	49 a	44 a	43 a	45 a	39 a	42 a	44 a	54 a	34 b

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Table 2. (Continued).

Harvest/ parameter	Time of barley emergence relative to the canola crop								Cultivar	
	-9 days	-7 days	-5 days	0 days	3 days	5 days	8 days	Weed-free	Tobin	Westar
Canola harvested 64 days after seeding										
Total weight (g/m^2)	284 b	287 b	365 b	316 b	299 b	301 b	319 b	496 a	342 a	326 a
% Leaves	27.8 a	29.1 a	26.4 a	28.4 a	27.7 a	28.9 a	28.0 a	26.4 a	19.2 b	36.2 a
% Stem	38.7 ab	37.4 b	41.3 a	40.1 ab	39.8 ab	38.5 ab	39.1 ab	40.9 ab	36.7 b	42.2 a
%Flowers	2.0 a	2.0 a	3.1 a	3.4 a	3.2 a	3.8 a	3.2 a	3.9 a	1.5 b	5.0 a
% Pods	22.6 a	22.3 a	19.4 a	17.7 a	19.2 a	18.9 a	19.8 a	18.6 a	33.6 a	6.5 b
% Root	8.9 b	9.2 ab	9.8 ab	10.4 a	10.0 ab	9.9 ab	9.9 ab	10.3 a	9.0 b	10.5 a
LAI (m^2/m^2)	2.00 c	2.11 bc	2.89 b	2.46 bc	2.45 bc	2.17 bc	2.66 bc	3.85 a	1.94 b	3.20 a
Stem area (m^2/m^2)	2.78 a	3.05 a	5.76 a	3.24 a	3.21 a	2.60 a	3.45 a	5.04 a	4.03 a	3.30 a
Pod area (m^2/m^2)	2.46 a	2.25 a	2.48 a	1.98 a	2.06 a	1.97 a	2.81 a	4.02 a	4.40 a	0.69 b
Plant height (cm)										
Tobin	67 a ♣	72 a ♣	72 a ♣	71 a ♣	70 a ♣	66 a ♣	72 a ♣	76 a ♣	-	-
Westar	68 ab ♣	70 a ♣	56 b ♥	69 ab ♣	64 ab ♣	62 ab ♣	68 ab ♣	68 ab ♣	-	-
Canola harvested 78 days after seeding										
Total weight (g/m^2)	407 b	396 b	507 b	472 b	408 b	387 b	457 b	825 a	474 a	494 a
% Leaves	13.0 a	12.8 a	10.6 a	12.0 a	12.7 a	12.8 a	11.6 a	10.7 a	7.9 b	16.2 a
% Stem	35.0 a	32.1 a	31.3 a	33.8 a	32.2 a	32.1 a	32.6 a	32.3 a	28.7 b	36.9 a
%Flowers	0.3 a	0.2 a	0.1 a	0.2 a	0.2 a	0.2 a	0.2 a	0.1 a	0.03 a	0.3 a
% Pods	45.1 a	48.2 a	51.6 a	47.4 a	46.5 a	47.7 a	48.4 a	49.6 a	57.4 a	38.7 b
% Root	6.6 a	6.6 a	6.4 a	6.6 a	7.4 a	7.1 a	7.2 a	7.2 a	6.0 b	7.8 a
LAI (m^2/m^2)	1.58 b	1.61 b	1.74 b	1.80 b	1.60 b	1.55 b	2.17 ab	2.61 a	1.09 b	2.56 a
Stem area (m^2/m^2)	3.19 b	2.92 b	3.85 b	3.99 b	2.94 b	2.59 b	3.97 b	5.81 a	3.77 a	3.59 a
Pod area (m^2/m^2)	4.93 c	4.33 c	6.49 bc	5.58 bc	4.76 c	5.42 bc	7.93 b	11.30 a	7.29 a	5.45 a
Plant height (cm)	77 a	77 a	75 a	76 a	74 a	76 a	74 a	78 a	75 a	77 a

. . . 3/

Table 2. (Continued).

Harvest/ parameter	Time of barley emergence relative to the canola crop								Cultivar	
	-9 days	-7 days	-5 days	0 days	3 days	5 days	8 days	Weed-free	Tobin	Westar
Canola final harvest										
Shoot weight (g/m^2)	436 c	532 b	618 b	608 b	631 b	621 b	630 b	920 a	593 a	655 a
% Stem	45.2 a	37.6 b	33.6 b	32.1 a	34.4 b	36.3 b	34.1 b	37.5 b	31.8 b	41.0 a
% Pods	54.8 b	62.4 a	66.4 a	67.9 a	65.6 a	63.6 a	65.9 a	62.5 a	68.2 a	59.0 b
Plant height (cm)	68 a	73 a	75 a	75 a	75 a	72 a	74 a	79 a	72 b	76 a

† Means across the columns within time of barley emergence or within canola cultivars followed by the same lower case letter are not significantly different at $P \leq 0.05$ according to Student-Newman-Keul's test. Means across canola cultivars within time of barley emergence followed by the same symbol are not significantly different at $P \leq 0.05$ according to Student-Newman-Keul's test.

§ Percent of total or total weight or shoot weight in component parts. Total weight extrapolated from a 0.21-m^2 harvest quadrat. Percent weight of component parts derived from five-plant subsamples. Shoot weight and component parts derived from 0.84-m^2 harvest quadrats.

¥ LAI, leaf area index.

Table 3. The proportion of dry matter in canola component parts, leaf area indices, plant heights for one harvest and final harvest during 1986.

Harvest/ parameter	Time of barley emergence relative to the canola crop -5 days	-3 days	-2 days	0 days	2 days	4 days	7 days	Weed-free	Cultivar Tobin	Westar
Canola harvested 64 days after seeding										
Total weight (g/m^2)	543 b[†]	616 b	688 b	718 b	721 b	780 b	746 b	1215 a	691 b	847 a
% Leaves[§]	17.3 bc	15.7 c	18.6 ab	12.0 a	17.0 bc	18.4 ab	19.9 a	18.3 ab	13.5 b	22.6 a
% Stem	57.9 a	55.8 a	57.3 a	56.1 a	57.7 a	58.8 a	58.6 a	56.8 a	56.5 a	58.4 a
% Flowers	2.6 ab	2.6 ab	2.2 b	2.5 ab	2.7 ab	3.5 a	3.4 a	2.8 ab	1.4 b	4.2 a
% Pods	13.4 abc	16.3 a	12.9 abc	15.0 ab	12.7 abc	9.4 bc	8.7 c	12.8 abc	20.2 a	4.4 b
% Root	8.7 a	9.6 a	9.0 a	9.4 a	9.3 a	9.8 a	9.4 a	9.4 a	8.3 b	10.4 a
LAI[Y] (m^2/m^2) Tobin	2.44 a ♣	2.45 a ♣	3.15 a ♣	2.99 a ♣	1.92 a ♥	3.03 a ♣	3.03 a ♥	3.26 a ♥	-	-
LAI (m^2/m^2) Westar	3.26 c ♣	3.14 c ♣	4.84 c ♣	4.46 bc ♣	5.66 bc ♣	5.30 bc ♣	7.89 ab ♣	9.34 a ♣	-	-
Stem area (m^2/m^2)	6.27 b	7.30 b	7.89 b	6.76 b	8.32 b	8.38 b	9.51 b	13.09 a	9.07 a	8.06 a
Pod area(m^2/m^2) Tobin	3.68 ab ♣	5.41 ab ♣	4.83 ab	8.03 a ♣	3.95 ab ♣	3.10 ab ♣	1.59 b ♣	7.64 ab ♣	-	-
Pod area (m^2/m^2) Westar	0.93 a ♥	0.90 a ♥	0.79 a ♥	0.79 a ♥	0.98 a ♥	0.91 a ♥	0.87 a ♥	1.39 a ♥	-	-
Plant height (cm)										
Tobin	113 a ♥	120 a ♣	122 a ♣	118 a ♥	113 a ♥	112 a ♥	115 a ♥	116 a ♥	-	-
Westar	133 ab ♣	121 b ♣	133 ab ♣	133 ab ♣	138 a ♣	136 a ♣	134 a ♣	132 ab ♣	-	-

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Table 3. (Continued).

Harvest/ parameter	-5 days	-3 days	-2 days	0 days	2 days	4 days	7 days	Weed-free	Tobin	Westar
	Time of barley emergence relative to the canola crop								Cultivar	
Canola final harvest										
Shoot weight (g/m^2)	510 e	587 de	692 cde	750 bcd	842 bcd	895 bc	1009 b	1425 a	887 a	829 a
% Stem	50.6 a	49.2 a	49.4 a	47.2 a	52.4 a	50.5 a	50.1 a	48.8 a	44.3 b	55.1 a
% Pods	49.4 a	50.8 a	50.6 a	52.8 a	47.6 a	49.5 a	49.9 a	51.2 a	55.7 a	44.9 b
Plant height (cm)	137 a	138 a	136 a	134 a	136 a	138 a	136 a	144 a	127 b	147 a

† Means across the columns within time of barley emergence or within canola cultivars followed by the same lower case letter are not significantly different at P≤0.05 according to Student-Newman-Keul's test. Means across canola cultivars within time of barley emergence followed by the same symbol are not significantly different at P≤0.05 according to Student-Newman-Keul's test.

§ Percent of total or total weight or shoot weight in component parts. Total weight extrapolated from a 0.21-m^2 harvest quadrat. Percent weight of component parts derived from five-plant subsamples. Shoot weight and component parts derived from 0.84-m^2 harvest quadrats.

¥ LAI, leaf area index.

is shaded by early emerging barley might become taller by partitioning more dry matter into stem growth.

The results from this experiment do not entirely support the above hypothesis. The amount of dry matter in canola leaves, stems, roots and pods was altered little by the time of barley emergence (Table 2). Where differences did occur, it was usually in the percentage of stem. This same observation was made by Major (1977) for weed-free *B. campestris* and *B. napus* grown in Lethbridge, Alberta. The individual canola plants grown with barley in this experiment were smaller (less dry matter) than weed-free canola plants, but each organ appeared to receive a similar proportion of the available dry matter.

Adams (1967) proposed that characteristic plant form is a function of a chain of sequential events. It appears that the developmental pattern of canola was not altered by the presence of barley or by the time it emerged in the crop, based on the percentage of dry matter in various organs. The phenological observations made on canola in 1986 also support this conclusion (Table 4). While the two canola cultivars differed in their rate of development, no difference in leaf appearance, flowering or pod initiation existed between any of the treatments, including the weed-free check.

Campbell and Kondra (1977) noted that earliness of initial growth stages in canola contributed to earliness of subsequent growth stages. This held true for the two canola cultivars used in this experiment. Tobin developed leaves more rapidly, bolted sooner and set pods before Westar (Table 2). The early production and filling of pods by Tobin clearly gives it an advantage in a short-season environment like Lacombe where pod filling can be limited by early frost.

The total amount of photosynthetic area is critical to dry matter production (Thurling, 1974a). Before the canola plants bolt, the assimilate source is essentially the laminar area of the true leaves (Brar and Thies, 1977). The time at which barley emerged did not alter canola leaf area prior to bolting (32-day harvest) (Table 2). After bolting, the leaf area of canola grown with barley was smaller than the leaf area of weed-free canola. By 64 days after canola seeding (in 1985), canola plants grown with barley had 40% less leaf area. The consequence of barley limiting leaf area was less stem material and less stem photosynthetic area.

Westar had a much higher leaf area than Tobin at all harvests. The maintenance of leafiness (a longer leaf area duration) by Westar could have several ramifications. If the orientation of leaves is such that self-shading is minimized it

Table 4. Stages of canola growth and plant height during the 1986 growing season.

Days after canola seeded	Stage[†]/cultivar		Time of barley emergence relative to the canola crop								Cultivar	
			-5 days	-3 days	-2 days	0 days	2 days	4 days	7 days	Weed-free	Tobin	Westar
9	Leaf	Tobin	1.1 a[§]	1.1 a	1.1 a	1.1 a	1.0 a	1.0 a	1.0 a	1.1 a	1.0 a	1.0 a
		Westar	1.0 a	1.0 a	1.0 a	1.0 a	1.0 a	1.0 a	1.0 a	1.0 a		
16	Leaf	Tobin	1.4 a	1.4 a	1.3 a	1.4 a	1.3 a	1.3 a	1.3 a	1.3 a	1.3 a	1.2 b
		Westar	1.2 a	1.2 a	1.2 a	1.2 a	1.2 a	1.2 a	1.2 a	1.2 a		
23	Leaf	Tobin	1.6 a	1.7 a	1.6 a	1.6 a	1.6 a	1.6 a	1.6 a	1.6 a	1.6 a	1.4 b
		Westar	1.4 a	1.4 a	1.4 a	1.4 a	1.4 a	1.4 a	1.4 a	1.4 a		
30	Leaf	Tobin	1.9 a	1.9 a	1.9 a	1.9 a	1.8 a	1.8 a	1.8 a	1.8 a	1.8 a	1.6 b
		Westar	1.6 a	1.6 a	1.6 a	1.7 a	1.6 a	1.7 a	1.6 a	1.6 a		
	Bud	Tobin	2.2 a	2.2 a	2.2 a	2.2 a	2.2 a	2.2 a	2.2 a	2.2 a	2.2 a	2.1 b
		Westar	2.1 a	2.0 a	2.2 a	2.2 a	2.0 a	2.1 a	2.1 a	2.1 a		
37	Flower	Tobin	3.0 a	3.0 a	3.0 a	3.0 a	3.0 a	3.0 a	3.0 a	3.0 a	3.0	-[Y]
	Bud	Westar	2.2 a	2.2 a	2.2 a	2.2 a	2.2 a	2.2 a	2.2 a	2.2 a	-	2.2
	Plant height (cm)	Tobin	65 a	65 a	67 a	64 a	60 a	63 a	61 a	57 a	63 a	33 b
		Westar	37 a	34 a	35 a	32 a	33 a	31 a	29 a	31 a		
44	Flower	Tobin	3.1 a	3.1 a	3.1 a	3.1 a	3.1 a	3.1 a	3.1 a	3.1 a	3.1	-
	Bud	Westar	2.2 a	2.2 a	2.2 a	2.2 a	2.2 a	2.2 a	2.2 a	2.2 a	-	2.2
	Plant height (cm)	Tobin	92 a	91 a	89 a	87 a	90 a	91 a	91 a	84 a	90 a	59 b
		Westar	60 a	61 a	62 a	60 a	56 a	61 a	57 a	54 a		

.../2

Table 4. (Continued).

Days after canola seeded	Stage/cultivar		Time of barley emergence relative to the canola crop								Cultivar	
			-5 days	-3 days	-2 days	0 days	2 days	4 days	7 days	Weed-free	Tobin	Westar
51	Flower	Tobin	3.2 a	3.2 a	3.2 a	3.2 a	3.2 a	3.2 a	3.2 a	3.2 a	3.2 a	3.0 b
	Flower	Westar	3.0 a	3.0 a	3.0 a	3.0 a	3.0 a	3.0 a	3.0 a	3.0 a		
	Plant height (cm)	Tobin	114 a	106 a	106 a	114 a	110 a	112 a	106 a	113 a	110 a	103 b
		Westar	105 a	105 a	103 a	108 a	100 a	100 a	101 a	101 a		
58	Seed	Tobin	3.4 a	4.0 a	4.0 a	4.0 a	4.0 a	4.0 a	4.0 a	4.0 a	4.0	-
	Flower	Westar	3.1 a	3.1 a	3.1 a	3.1 a	3.1 a	3.1 a	3.1 a	3.1 a	-	3.1
	Plant height (cm)	Tobin	116 a	118 a	120 a	119 a	119 a	119 a	128 a	124 a	121 a	120 a
		Westar	113 a	116 a	124 a	127 a	118 a	123 a	124 a	126 a		
Final harvest	Plant height (cm)	Tobin	129 a	125 a	134 a	125 a	124 a	124 a	126 a	133 a	127 b	147 a
		Westar	142 a	140 a	143 a	144 a	147 a	152 a	147 a	155 a		

Number	Description	Number	Description
1.0	Emergence and cotyledon expansion	3.1	Peduncle elongating, many flowers open
1.1 to 1.9	First true leaf to all true leaves formed	3.2	Lower pods elongating
2.1	Terminal bud enlarging	3.3	Lower pods starting to fill
2.2	Bud raised above rosette level	3.4	Seeds enlarging, all buds open
2.3	Pedicels elongating	4.0	Seeds in lower pods full size, translucent
2.4	Buds yellowing	4.1-4.5	More stages of seed development
3.0	First flowers opening on terminal bud	5.0	Brown pods brittle, stems dry

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† Growth stages from Berkenkamp, 1973.

§ Means across the columns within time of barley emergence or within canola cultivars followed by the same letter are not significantly different at P≤0.05 according to Student-Newman-Keul's test.

Y -, not applicable.

may mean more dry matter production. It also could mean that Westar might limit weed growth and development late in the season because of inter-crop shading.

Pod production is dependent on stem and leaf assimilate (Rood *et al.*, 1984). Once seeds begin to develop, they rely on photosynthate from the pod wall for filling (Major *et al.*, 1978; Inanaga *et al.*, 1979). Consequently, pod photosynthetic area is also a factor in final seed yield. Like leaf area, pod area was reduced by barley. The pod area of canola grown with barley was approximately 50% of weed-free canola pod area in 1985 (Table 2). There was some indication that the pod area was less when barley emerged before the canola crop. In this experiment, Tobin had a higher pod area than Westar (Tables 2 and 3). This was likely due to the basic difference in pod number between the two cultivars and differences in maturity.

Correlation of several canola growth parameters with final seed yield confirmed the basic pattern of yield development in canola. Canola plant dry weight at each harvest was always highly correlated with final seed yield (Table 5). The size and importance of various organs contributing to dry matter production changed through the growing season.

Even though there was up to 15 days difference in the seeding dates of the barley, barley planted at each date had the same sequential development pattern. It appeared that this pattern was compressed in the late planted barley (Table 6). Barley that emerged eight days after the crop, headed at approximately the same time as barley that had emerged before the crop. The phenological observations made in 1986 suggest that this is due to the faster appearance of new leaves in the barley that was seeded after the crop (Table 7). A similar growth phenomenon occurs with tillers on individual barley plants. They produce fewer leaves so that tiller spikes are initiated at a similar time as the spike of the main shoot (Wych *et al.*, 1985).

One basic difference between the early emerging and late emerging barley plants was the total amount of dry matter produced (Tables 6 and 8). Total plant weight declined as barley emergence was delayed. Barley plant stand averaged 60±2 and 64±1 plants/m^2 in 1985 and 1986, respectively. By final harvest, the barley plant stand was reduced by 2% in 1985 and 11% in 1986. No differences in plant stand were detected between the barley treatments however the trend was to greater barley plant loss in later emerging barley treatments. The decline in total weight was a combination of plant mortality and reduction in barley plant size.

Table 5. Correlation between canola seed yield and total weight, leaf area index, stem area and pod area for four harvests made during the growing season in 1985.

Parameter	Cultivar	Days after canola seeded† 32	50	64	78
Total weight (g/m^2)	Tobin	0.98**	0.97**	0.98**	0.98**
	Westar	0.91**	0.91**	0.91**	0.91**
LAI (m^2/m^2)	Tobin	0.13	0.32	0.42*	0.33
	Westar	0.09	0.52**	0.42*	0.24
Stem area (m^2/m^2)	Tobin	0.11	0.18	0.09	0.35
	Westar	-0.17	0.49**	0.36*	0.38*
Pod area (m^2/m^2)	Tobin	-	-	0.40*	0.42*
	Westar	-	-	-	0.56**

† **, significant at P≤0.01; *, significant at P≤0.05.

Table 6. The proportion of dry matter in barley component parts, leaf area indices, plant heights and number of tillers at four harvests and final harvest during 1985.

Harvest	Time of barley emergence relative to the canola crop							Cultivar	
	-9 days	-7 days	-5 days	0 days	3 days	5 days	8 days	Tobin	Westar
Barley in canola harvested 32 days after canola seeded									
Total weight (g/m^2)	64.4 a	57.8 a	39.8 b	21.6 bc	31.2 b	12.1 c	13.4 c	31.2 a	39.2 a
% Leaves	58.9 a	59.2 a	61.3 a	63.8 a	64.9 a	63.2 a	63.2 a	64.0 a	60.3 a
% Stem	22.4 a	22.5 a	20.4 a	18.4 a	18.5 a	12.7 b	14.1 b	18.9 a	18.1 a
% Root	18.7 a	18.3 a	18.3 a	17.8 a	16.6 a	24.1 a	22.7 a	17.1 a	21.6 a
LAI (m^2/m^2)	0.85 a	0.77 a	0.58 ab	0.34 bc	0.43 bc	0.16 c	0.18 c	0.39 a	0.55 a
Plant height (cm)	28 a	30 a	26 a	24 a	25 a	17 a	19 a	23 a	25 a
Tillers/plant (#)	4 a	4 a	3 ab	3 ab	3 ab	2 b	2 b	3 a	3 a
Barley in canola harvested 50 days after canola seeded									
Total weight (g/m^2)	351 a	280 ab	233 bc	186 dc	150 dc	105 d	101 d	192 a	210 a
% Leaves	27.2 e	28.5 de	30.9 d	33.8 c	36.8 b	37.9 b	41.2 a	34.1 a	33.2 a
% Stem	54.4 a	53.6 a	51.1 ab	50.0 ab	50.5 ab	46.1 bc	43.2 c	48.2 a	51.5 a
% Root	18.4 a	17.9 a	18.0 a	16.2 a	12.7 a	16.0 a	15.6 a	17.6 a	15.2 a
LAI (m^2/m^2) In Tobin	1.44 ab ▼	1.18 c ▼	1.49 a ♣	1.36 b ♣	0.94 d ♣	0.99 d ♣	1.00 d ♣	-	-
LAI (m^2/m^2) In Westar	2.37 a ♣	1.46 b ♣	1.57 b ♣	1.17 c ▼	1.08 c ♣	0.79 d ▼	0.77 d ▼	-	-
Plant height (cm)	58 a	63 a	61 a	56 a	63 a	48 a	50 a	58 a	56 a
Tillers/plant (#)	3 a	3 a	3 a	3 a	3 a	3 a	3 a	3 a	3 a

. . . 2/

Table 6. (Continued).

Harvest	Time of barley emergence relative to the canola crop -9 days	-7 days	-5 days	0 days	3 days	5 days	8 days	Cultivar Tobin	Westar
Barley in canola harvested 64 days after canola seeded									
Total weight (g/m^2)	415 a	422 a	305 abc	327 ab	275 bc	179 c	237 bc	295 a	327 a
% Leaves	11.9 b	12.6 b	14.0 b	13.5 b	15.3 ab	18.1 a	16.9 a	15.1 a	14.0 a
% Dry Leaves	4.1 a	4.7 a	4.7 a	4.4 a	4.4 a	2.5 b	3.3 ab	4.5 a	3.6 b
% Stem	35.2 a	36.1 a	38.6 a	44.4 a	41.1 a	40.3 a	42.7 a	42.2 a	37.5 a
% Heads	28.3 a	25.3 ab	24.3 ab	20.7 bcd	21.8 bc	16.6 d	18.5 cd	22.2 a	22.5 a
% Root	20.4 abc	21.3 a	18.4 bc	16.9 c	17.4 c	22.5 a	18.6 bc	16.1 b	22.4 a
LAI (m^2/m^2)	1.21 a	1.17 a	0.97 ab	0.96 ab	0.98 ab	0.62 b	0.89 ab	1.05 a	0.91 a
Plant height (cm)	75 a	77 a	74 a	78 a	76 a	68 a	77 a	76 a	75 a
Tillers/plant (#)	3 a	3 a	3 a	2 a	3 a	3 a	3 a	3 a	3 a
Barley in canola harvested 78 days after canola seeded									
Total weight (g/m^2)	513 a	535 a	472 a	396 a	358 a	308 a	328 a	387 a	442 a
% Leaves	7.0 a	7.3 a	7.5 a	7.1 a	8.5 a	8.7 a	8.0 a	8.3 a	7.2 b
% Dry Leaves	5.7 a	5.6 a	5.7 a	5.3 a	5.2 a	4.8 a	5.1 a	7.1 a	6.1 a
% Stem	27.1 d	28.5 d	28.9 d	29.5 d	31.6 c	36.2 a	33.7 b	31.7 a	29.8 a
% Heads	54.4 a	53.1 ab	49.7 b	52.4 ab	49.3 b	42.4 c	45.3 c	47.3 b	51.7 a
% Root	5.8 b	5.5 b	8.1 a	5.7 b	5.2 b	7.9 a	7.8 a	5.5 a	5.2 a
LAI (m^2/m^2)	0.80 a	0.76 a	0.83 a	0.63 a	0.56 a	0.51 a	0.57 a	0.65 a	0.68 a
Plant height (cm)	76 a	79 a	75 a	79 a	75 a	76 a	75 a	78 a	75 a
Tillers/plant (#)	2 a	3 a	2 a	2 a	2 a	3 a	3 a	2 a	2 a

. . . 3/

Table 6. (Continued).

Harvest	Time of barley emergence relative to the canola crop							Cultivar	
	-9 days	-7 days	-5 days	0 days	3 days	5 days	8 days	Tobin	Westar
Barley in canola final harvest									
Shoot weight (g/m^2)	509 a	479 a	351 b	359 b	335 b	307 b	291 b	398 a	353 a
% Stem	35.9 a	36.6 a	38.2 a	35.2 a	37.5 a	36.2 a	37.7 b	38.2 a	35.3 a
% Heads	64.1 a	63.4 a	61.8 a	64.8 a	62.5 a	63.8 c	62.3 c	61.8 b	64.7 a
Plant height (cm)	74 a	72 a	74 a	74 a	74 a	70 a	69 a	75 a	70 b

† Means across the columns within time of barley emergence or within canola cultivars followed by the same lower case letter are not significantly different at P≤0.05 according to Student-Newman-Keul's test. Means across canola cultivars within time of barley emergence followed by the same symbol are not significantly different at P≤0.05 according to Student-Newman-Keul's test.

§ Percent of total or total weight or shoot weight in component parts. Total weight extrapolated from a 0.21-m^2 harvest quadrat. Percent weight of component parts derived from five-plant subsamples. Shoot weight and component parts derived from 0.84-m^2 harvest quadrats.

¥ LAI, leaf area index.

Table 7. Stages of barley growth and plant height during the 1986 growing season.

Days after canola seeded[§]	Stage[†]	Time of barley emergence relative to the canola crop							Cultivar	
		-5 days	-3 days	-2 days	0 days	2 days	4 days	7 days	Barley in Tobin	Barley in Westar
9	Germination	C[§] a[¥]	C a	C a	C a	C a	07 b	03 c	-	-
	Seedling growth	13 a	12 b	12 b	12 b	11 c	-	-	-	-
	Tillering	21 a	20 b	20 b	20 b	20 b	-	-	-	-
16	Seedling growth	14 a	14 a	13 b	13 b	12 c	12 c	11 d	13 a	13 a
	Tillering	22 a	22 a	21 b	21 b	20 c	20 c	20 c	21 a	21 a
23	Seedling growth	15 a	15 a	15 a	14 b	14 b	14 b	13 c	14 a	14 a
	Tillering	24 a	23 ab	23 ab	23 ab	22 ab	20 b	21 ab	23 a	22 a
30	Seedling growth	17 a	16 a	16 a	16 a	16 a	15 b	14 b	16 a	16 a
	Tillering	26 a	25 ab	25 ab	24 ab	24 ab	23 ab	22 b	25 a	24 a
	Stem elongation	34 a	33 ab	33 ab	33 ab	33 ab	32 bc	31 c	33 a	32 a
37	Seedling growth	C a	C a	C a	18 ab	17 bc	16 c	16 c	18 a	18 a
	Tillering	27 a	26 a	26 a	25 ab	25 ab	24 b	24 b	26 a	25 a
	Stem elongation	C a	C a	C a	36 b	35 b	35 b	34 b	-	-
	Booting	43 a	42 a	40 b	-	-	-	-	-	-
	Plant height (cm)	53 a	48 ab	47 ab	41 abc	39 cd	34 cd	28 d	42 a	40 a
44	Seedling growth	C a	C a	C a	C a	C a	C a	17 b	-	-
	Stem elongation	C a	C a	C a	C a	C a	C a	35 b	-	-
	Booting	C a	C a	47 b	43 c	42 d	41 d	-	-	-
	Inflorescence emergence	55 a	50 b	-	-	-	-	-	-	-
	Plant height (cm)	80 a	77 ab	70 b	57 c	56 c	54 c	46 d	63 a	62 a

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Table 7. (Continued).

Days after canola seeded	Stage	Time of barley emergence relative to the canola crop							Cultivar	
		-5 days	-3 days	-2 days	0 days	2 days	4 days	7 days	Barley in Tobin	Barley in Westar
51	Booting	Ca	Ca	Ca	Ca	Ca	Ca	46 b	-	-
	Inflorescence emergence	Ca	Ca	Ca	Ca	54 a	50 ab	-	-	-
	Anthesis	69 a	68 a	66 a	-	-	-	-	-	-
	Plant height (cm)	105 a	102 a	100 a	90 b	86 a	77 c	75 c	92 a	90 a
58	Inflorescence emergence	Ca	Ca	Ca	Ca	Ca	Ca	57 a	-	-
	Anthesis	Ca	Ca	Ca	Ca	Ca	Ca	-	-	-
	Milk development	70 a	70 a	-	-	-	-	-	-	-
	Plant height (cm)	114 a	114 a	112 a	114 a	110 a	105 a	95 b	109 a	109 a
Final Harvest										
	Plant height (cm)	109 b	114 ab	116 ab	115 ab	117 ab	119 a	121 a	119 a	113 b
	Head-bearing tillers/plant	4 a	4 a	3 ab	3 ab	3 ab	2 c	2 c	3 a	3 a

† Growth stages recorded on 10 plants/treatment using the scale of Zadoks *et al.* (1974): 03, imbibition complete; 07, coleoptile emerged from caryopsis; 10 to 19, number of true leaves unfolded; 20 to 29, number of tillers on the main shoot; 31 to 36, stem elongation, number of detectable nodes; 40 to 49, booting, flag leaf extension to awns visible; 50 to 59, first spikelet visible to inflorescence totally emerged; 60 to 69, beginning to completion of anthesis; 70 to 79, caryopsis water ripe to late milk stage.

§ C, stage completed; -, stage not reached or not applicable.

Y Means across the columns within time of barley emergence or within canola cultivars followed by the same letter are not significantly different at $P \leq 0.05$ according to Student-Newman-Keul's test.

The size difference was discernible by the number of tillers present on the plants at the mid-season harvests. Early emerging barley produced more tillers in total than late emerging barley and also had more spikes at final harvest. While the barley that emerged after the crop did not produce as many tillers as the early emerging barley, these plants generally maintained the tillers that were produced.

The leaf area indices of the barley plants were also decreased when barley emerged after the crop in 1985 but not in 1986 (Tables 6 and 8). Differences in tiller number that were evident in the phenological measurements made in 1986 (Table 7) could be responsible for the leaf areas observed. For 1985, when tiller number was the same in the later harvests (Table 6), leaf area differences would be due to tiller size. Both total plant weight and leaf area indices (especially for barley grown in Westar) during the season were highly correlated with final seed yield (Table 9).

Plant yield. Canola seed yield increased as barley emergence, relative to crop emergence, was delayed (Figure 1). Tobin yield increased 3.3 g/m^2 in 1985 and 6.0 g/m^2 in 1986 for each day barley emergence was delayed. Westar yield increased 3.6 g/m^2/day in 1985, however, no relationship was evident in 1986 (Table 10). The highest canola yields occurred when barley emerged eight days after the crop (Tobin, 189 g/m^2, Westar 176 g/m^2). These yields still were only 67% and 69% of the weed-free seed yield for Tobin and Westar, respectively (Table 10). When barley emerged nine days before the crop, the seed yields were 47% and 45% of their respective weed-free checks. Similar results were observed for Tobin in 1986. Tobin yield was 37% and 64% of the weed-free crop when barley emerged five days before and seven days after the crop, respectively. The mean Westar yield in the barley treatments was 42±4 g/m^2 in 1986. This value was 42% of weed-free Westar seed yield (99±21 g/m^2).

Tobin produced more seed than Westar at any of the times of barley emergence in 1985. Tobin yielded 15% more than Westar when barley emerged nine days before the crop, 10% more when the crop and weed emerged simultaneously and 7% more when barley emerged eight days after the crop.

Time of barley emergence was generally the most important variable contributing to the equations predicting canola seed yield (Table 10). Although the canola and barley were seeded at the same densities, plant stand did account for some of the variability in seed yield, even though no statistical significant differences were detected between the treatments. In 1985, for instance, Tobin emergence count and

Table 8. The proportion of dry matter in barley component parts, leaf area indices, plant heights, number of tillers for one harvest and final harvest during 1986.

Harvest/ parameter	Time of barley emergence relative to the canola crop							Cultivar	
	-5 days	-3 days	-2 days	0 days	2 days	4 days	7 days	Tobin	Westar
Barley in canola harvested 64 days after canola seeded									
Total weight (g/m^2)	635 a[†]	577 a	505 b	412 c	371 c	345 c	265 d	427 a	431 a
% Leaves	9.7 d	11.0 cd	11.9 cd	11.6 cd	12.6 c	14.9 b	16.6 a	13.6 a	12.0 b
% Dry Leaves	5.1 a	4.2 a	4.8 a	4.9 a	5.8 a	4.2 a	5.9 a	4.8 a	5.3 a
% Stem	49.4 b	49.7 b	52.0 ab	52.1 ab	53.5 a	54.1 a	54.0 a	52.1 a	52.6 a
% Heads	28.2 a	26.6 a	24.0 b	23.3 b	20.6 c	19.1 c	16.6 d	21.6 a	22.7 a
% Root	7.6 a	8.5 a	7.3 a	8.1 a	7.5 a	7.7 a	7.0 a	7.8 a	7.4 a
LAI	1.55 a	1.86 a	1.37 a	1.20 a	1.53 a	1.64 a	1.45 a	1.59 a	1.40 a
Plant height (cm)	116 a	116 a	119 a	119 a	117 a	118 a	116 a	118 a	117 a
Tillers/plant (#)	4 a	4 a	3 ab	2 b	2 b	2 b	2 b	3 a	3 a
Barley in canola final harvest									
Shoot weight (g/m^2)									
In Tobin	814 a ♣	689 ab ♣	651 ab ♣	434 bc ♣	520 bc ♣	455 bc ♣	308 c ♣	-	-
In Westar	751 a ♣	620 a ♣	488 ab ♣	465 ab ♣	463 ab ♣	202 b ♥	277 b ♣	-	-
% Stem	45.6 a	46.3 a	46.6 a	46.8 a	46.5 a	49.5 a	48.9 a	46.2 b	48.2 a
% Heads	54.4 a	53.7 a	53.4 a	53.2 a	53.5 a	50.5 a	51.1 a	53.8 a	51.8 b
Plant height (cm)	109 b	114 ab	116 ab	115 ab	117 ab	119 a	121 a	119 a	113 b

[†] Means across the columns within time of barley emergence or within canola cultivars followed by the same lower case letter are not significantly different at P≤0.05 according to Student-Newman-Keul's test. Means across canola cultivars within time of barley emergence followed by the same symbol are not significantly different at P≤0.05 according to Student-Newman-Keul's test.

[§] Percent of total or total weight or shoot weight in component parts. Total weight extrapolated from a 0.21-m^2 harvest quadrat. Percent weight of component parts derived from five-plant subsamples. Shoot weight and component parts derived from 0.84-m^2 harvest quadrats.

[Y] LAI, leaf area index.

Table 9. Correlation between barley seed yield and total weight, leaf area index and stem area for four harvests made during the growing season in 1985.

Parameter	Cultivar	Days after canola seeded† 32	50	64	78
Total weight (g/m^2)	Barley in Tobin	0.99**	0.99**	0.99**	0.99**
	Barley in Westar	0.99**	0.99**	0.99**	0.99**
LAI (m^2/m^2)	Barley in Tobin	0.47*	0.20	0.40*	0.21
	Barley in Westar	0.58**	0.61**	0.62**	0.54**

† **, significant at P≤0.01; *, significant at P≤0.05.

Figure 1. Relationship between seed yield and time of barley emergence for canola (closed symbols, solid lines) and barley (open symbols, broken lines) grown togther in 1985 and 1986.

Lines predicted from regression equations assume a mean crop density of 98 plants/m^2 and a mean barley density of 62 plants/m^2.
Mean weed-free yields: Tobin 1985, 281.2 g/m^2; Westar, 1985 254.2 g/m^2; Tobin, 1986 252.2 g/m^2; Westar, 1986, 98.8 g/m^2.

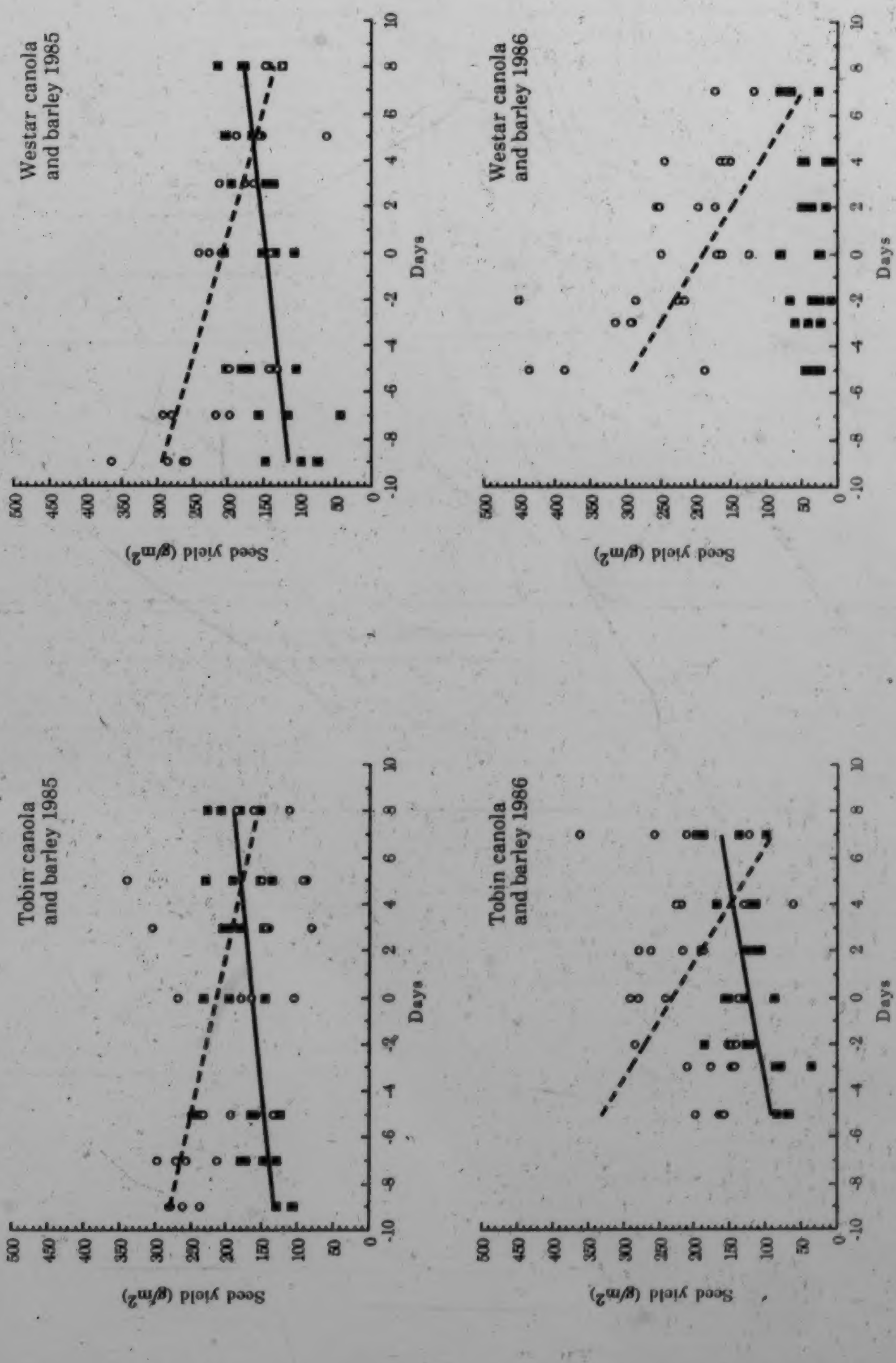

Westar canola and barley 1985
Westar canola and barley 1986
Tobin canola and barley 1985
Tobin canola and barley 1986
Seed yield (g/m²)
Days
0
50
100
150
200
250
300
350
400
450
500
-10
-8
-6
-4
-2
0
2
4
6
8
10

Table 10. Relationship between canola seed yield and time of barley emergence, canola emergence count and barley emergence count.

Year	Cultivar	Weed-free check (g/m^2)	Regression coefficients[†]				R^2	Significance[§]
			a	*b*	*c*	*d*		
1985	Tobin	281	183.91	3.31 (0.87)[Y]	0.65 (0.22)	-1.38 (0.44)	0.60	**
	Westar	254	254.36	3.61 (1.01)	-	-1.73 (0.49)	0.53	**
1986	Tobin	252	120.93	6.00 (1.93)	-	-	0.31	*
	Westar	99	no relationship					

Standard partial regression coefficients

Year	Cultivar	Days	Crop emergence count	Barley emergence count
1985	Tobin	0.50	0.37	-0.42
	Westar	0.49	-	-0.50
1986	Tobin	0.69	-	-
	Westar	-	-	-

[†] Following the model, $Y = a + bD + cC + dB$ where Y is the seed yield (g/m^2); D, days barley emerged before or after the crop; C, crop emergence count ($\#/m^2$); B, barley emergence count ($\#/m^2$), n=28.

[§] **, significant at $P \leq 0.01$; *, significant at $P \leq 0.05$.

[Y] Standard error bracketed.

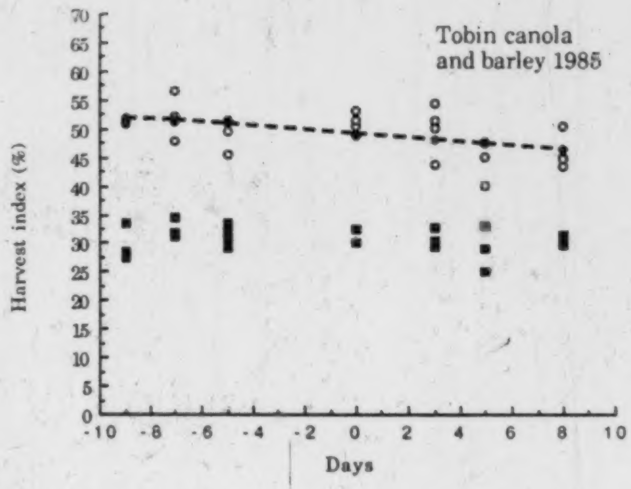
barley emergence count were almost as important as the time factor in determining Tobin seed yield (determined by the relative size of the partial regression coefficients). As a rule, increased canola stand resulted in higher canola yields while higher barley densities reduced canola seed yield.

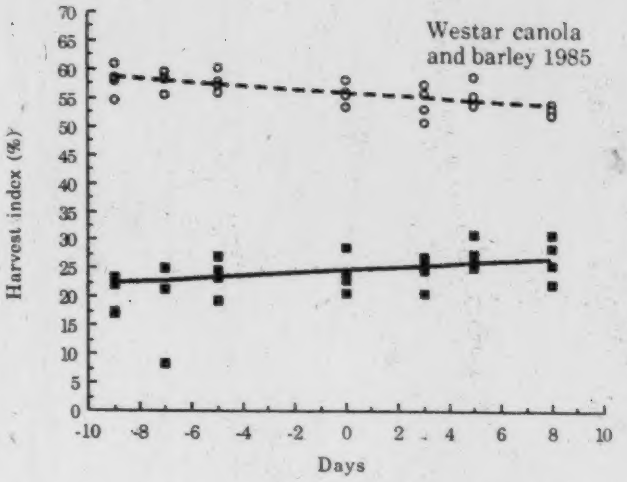
Harvest index is a measure of the efficiency with which photosynthate from assimilatory organs (leaves, stems, pods) is converted into organs of economic value (seed) (Thakral *et al.*, 1983). Harvest index of canola generally was not altered by the presence of barley or the time of barley emergence (Figure 2). Partitioning of dry matter can partially explain the lower seed yield observed in Tobin in 1986. Even though shoot dry matter was greater in 1986, the harvest index was approximately half (15.3±0.7) that observed in 1985 (30.9±0.4). Westar harvest index in 1985 increased as barley emergence time relative to the crop increased (Harvest index = 41.63 + 0.26 x days - 0.08 x crop emergence count - 0.14 x barley emergence count, R^2=0.60**). Westar harvest index was only 20.0±1.7 when barley emerged nine days before the crop and rose to 27.0±1.9 when barley emerged eight days after the crop. The increments in shoot weight as barley emergence was delayed combined with a larger proportion of dry matter going to the seed accounted for Westar's seed yield in 1985. The low Westar harvest index (6.1±1.3) and associated seed yield in 1986 indicated that there were some dry matter partitioning problems in that year. From the 64-day mid-season harvested it appeared that pod set was slower in 1986. This was likely due to the dry weather in July (Appendix 3). Pod production was stimulated in August by moisture. This is confirmed by the percentage of dry matter in pods at final harvest in 1986 (Table 3) compared to 1985 (Table 2). The yield potential was set, but final seed yield was limited by the amount of time available to set and fill seed in the pods.

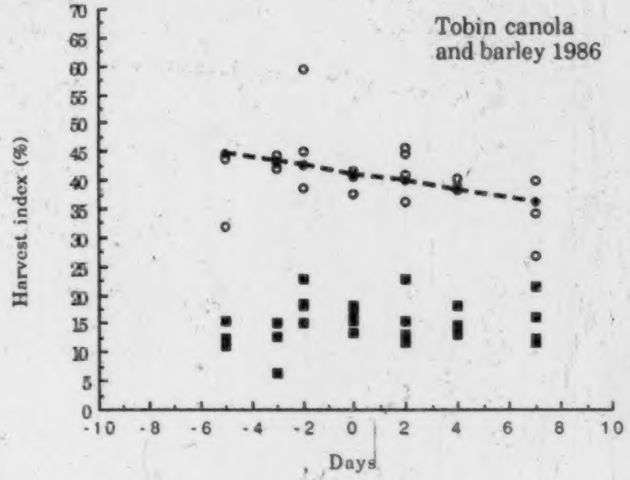
In the situation where harvest index is unchanged by time of weed emergence, the only way to increase canola seed yield would be to increase total biomass. For canola, under weedy conditions, the quickest way to increase biomass would be to remove the weeds. From a breeder's point of view, higher seed yield could be achieved by identifying canola cultivars with higher harvest indices or cultivars that produce more dry matter in the presence of weeds. Currently, canola cultivars with the highest dry matter production potential are unsuccessful in short-season environments because they require a longer growing season (Kasa and Kondra, 1986).

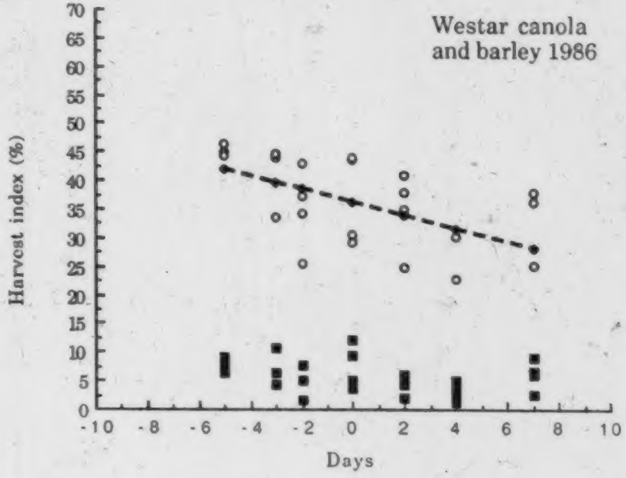
Figure 2. Relationship between harvest index and time of barley emergence for canola (closed symbols, solid lines) and barley (open symbols, broken lines) grown togther in 1985 and 1986.

Lines predicted from regression equations assume a mean crop density of 98 plants/m^2 and a mean barley density of 62 plants/m^2.


Tobin canola
and barley 1985
Harvest index (%)
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-10
-8
-6
-4
-2
0
2
4
6
8
10
Days


Westar canola
and barley 1985
Harvest index (%)
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-10
-8
-6
-4
-2
0
2
4
6
8
10
Days


Tobin canola
and barley 1986
Harvest index (%)
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-10
-8
-6
-4
-2
0
2
4
6
8
10
Days


Westar canola
and barley 1986
Harvest index (%)
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-10
-8
-6
-4
-2
0
2
4
6
8
10
Days

The size of the individual seeds contributing to the overall seed yield can reflect stress on the plants at filling time. Tobin seeds appeared to be filled equally in all treatments, as no relationship between Tobin 1000-seed weight and time of barley emergence was evident (Figure 3). Tobin seeds, on average, were larger in 1985 (3.14±0.1 g/1000) than in 1986 (2.86±0.2 g/1000). There was also no relationship between Westar 1000-seed weight and time of barley emergence in 1985. Characteristic of the species, Westar seeds were larger (3.71±0.2) g/1000) than those of Tobin in 1985. In 1986, the weight of Westar seeds declined as barley emergence was delayed (1000-seed weight=2.971 - 0.033 x Days, R^2=0.27*). This suggests that Westar was sink-limited by the early-emerging barley.

The separation of the subsample plants into their yield components should assist in understanding of the development of the final seed yield. Per plant seed yield and seed yield/m^2 were correlated in 1985, but not in 1986 (Figure 4). Therefore, no inference of a connection between per plant yield components and overall canola yield will be made on the 1986 data.

Early-emerging barley limited branching and pod production by individual canola plants in 1985. Tobin and Westar branch count and pod count increased when barley emergence was delayed (Figure 5). The total number of branches on Tobin ranged from three, when barley emerged nine days before the crop, to seven when barley emerged eight days after the crop. Westar had fewer branches overall, and the number of branches per plant ranged from one to four in this cultivar.

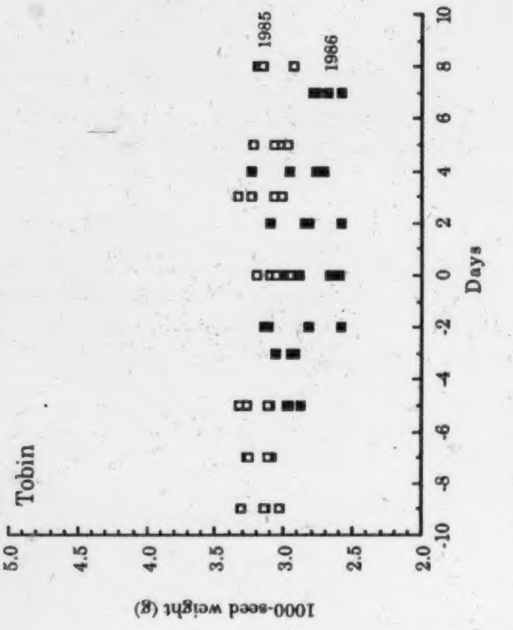
Campbell and Kondra (1978a) reported that the number of secondary and tertiary branches was closely associated with final seed yield of weed-free *B. napus*. While the total number of branches per canola plant increased as barley emergence was delayed, the total number of branches accounted for very little of the variability observed in seed yield per plant (Table 11).

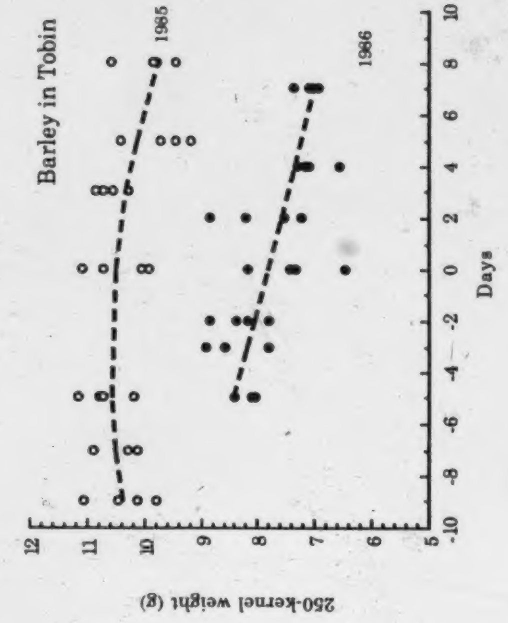
The canola plants had fewer pods when barley emerged before the crop (Figure 5). Tobin had more pods, for any date of barley emergence, than Westar. This is characteristic of the species. Tobin pod count ranged from 45 pods per plant for the earliest time of barley emergence to 102 pods for the latest emergence time. Westar had only 14 pods per plant when barley emerged nine days before the crop to over 30 when it emerged after the crop.

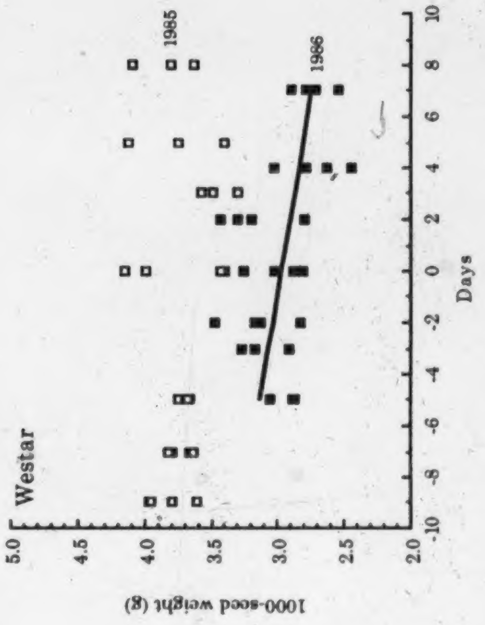
Pod number is the most variable component of canola yield and most susceptible to stress imposed by the environment (Clarke and Simpson, 1978b). In 1985,

Figure 3. **Relationship between canola 1000-seed weight and barley 250-kernel weight, and time of barley emergence canola for canola and barley grown togther in 1985 and 1986.**

Lines predicted from regression equations assume a mean crop density of 98 plants/m^2 and a mean barley density of 62 plants/m^2.


Tobin
1000-seed weight (g)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
-10
-8
-6
-4
-2
0
2
4
6
8
10
Days
1985
1986


Barley in Tobin
250-kernel weight (g)
12
11
10
9
8
7
6
5
-10
-8
-6
-4
-2
0
2
4
6
8
10
Days
1985
1986


Westar
1000-seed weight (g)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
-10
-8
-6
-4
-2
0
2
4
6
8
10
Days
1985
1986

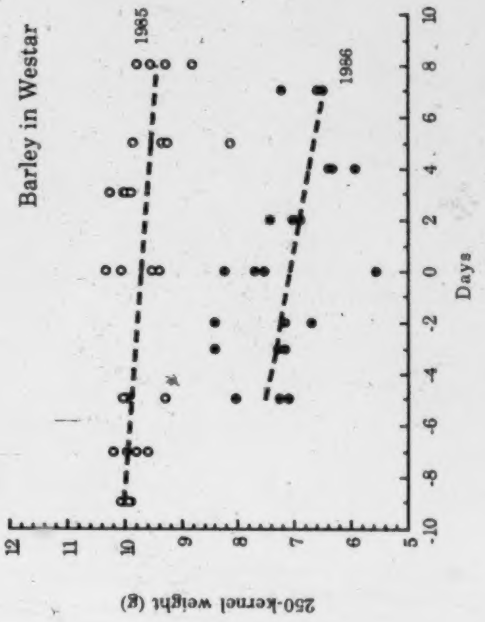
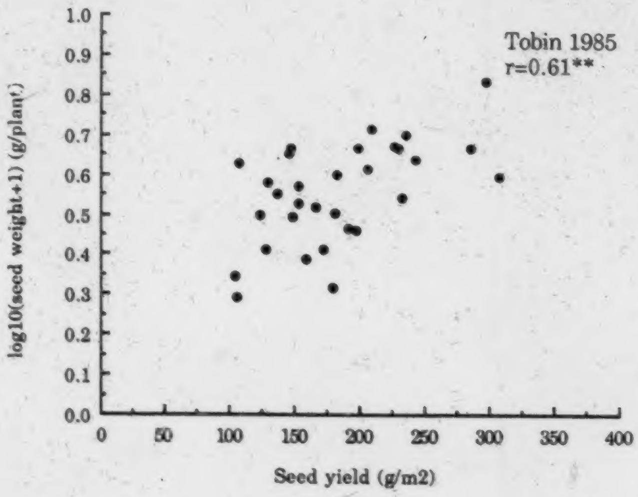
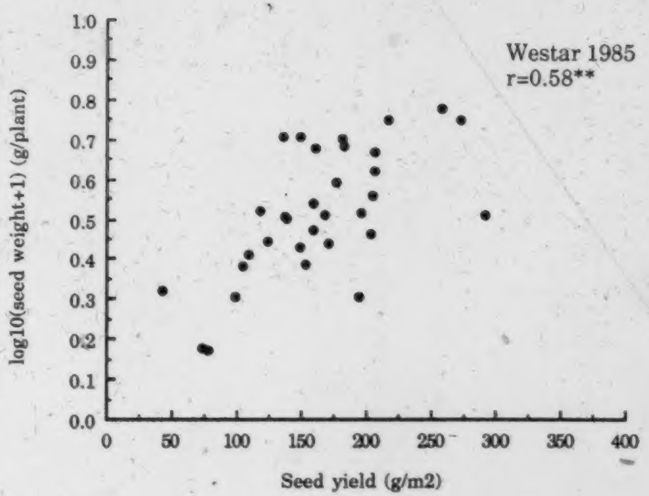
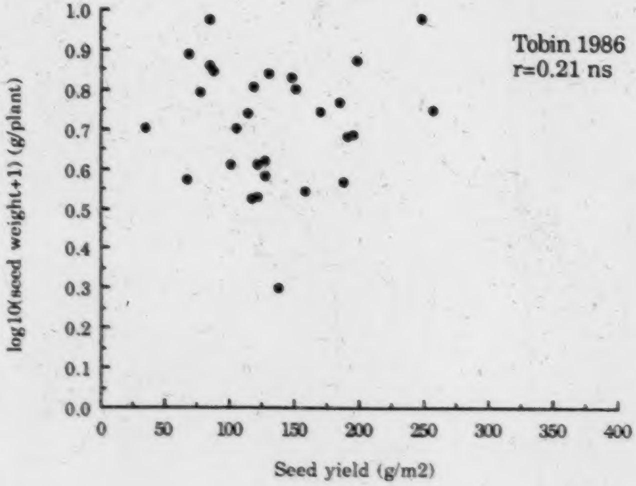

Barley in Westar
250-kernel weight (g)
12
11
10
9
8
7
6
5
-10
-8
-6
-4
-2
0
2
4
6
8
10
Days
1985
1986

Figure 4. Correlation between canola seed yield and mean canola seed yield of the five-plant harvest sub-sample in 1985 and 1986.


Tobin 1985
r=0.61**
log10(seed weight+1) (g/plant)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
50
100
150
200
250
300
350
400
Seed yield (g/m2)


Westar 1985
r=0.58**
log10(seed weight+1) (g/plant)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
50
100
150
200
250
300
350
400
Seed yield (g/m2)


Tobin 1986
r=0.21 ns
log10(seed weight+1) (g/plant)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
50
100
150
200
250
300
350
400
Seed yield (g/m2)

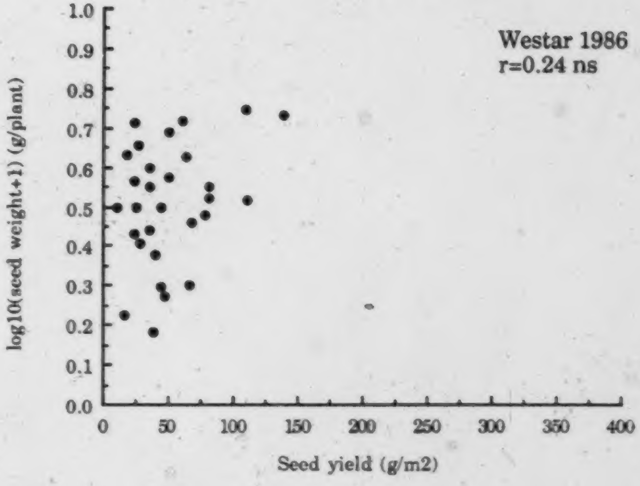
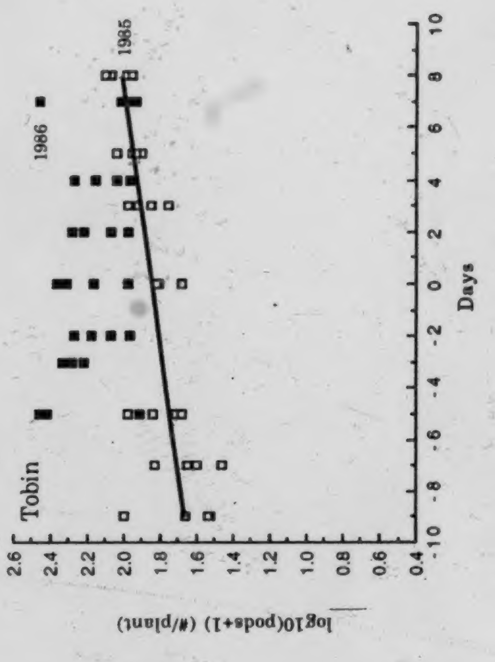

Westar 1986
r=0.24 ns
log10(seed weight+1) (g/plant)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
50
100
150
200
250
300
350
400
Seed yield (g/m2)

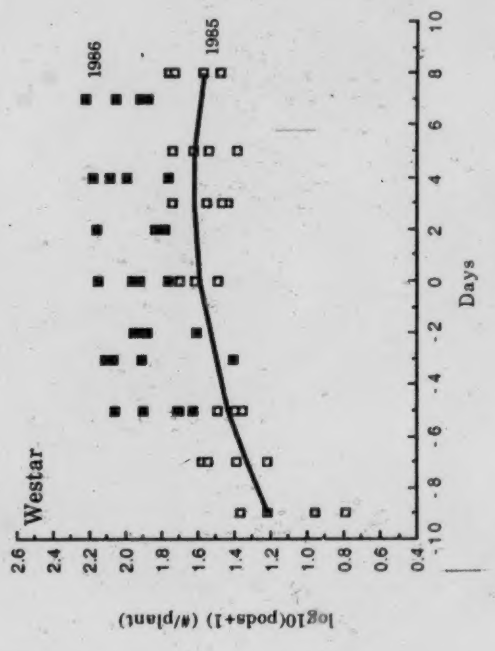
Figure 5. Relationship between $\log_{10}$(pods+1) and $\log_{10}$(total branches+1), and time of barley emergence for Tobin and Westar canola grown in 1985 (open symbols) and 1986 (closed symbols).

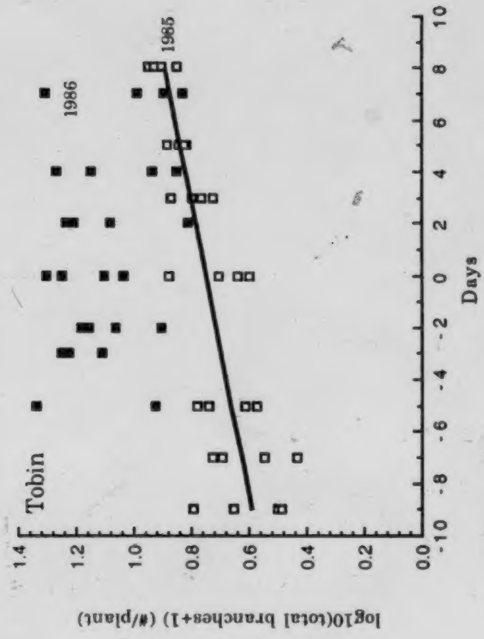
1985

Tobin $\log_{10}$(pods+1) /plant = 1.85 + 0.02 (0.004) x Days, R^2=0.52**
Westar $\log_{10}$(pods+1)/plant = 1.59 + 0.02 (0.004) x Days - 0.003 (0.0009) x Days^2,R^2=0.48**
Tobin $\log_{10}$(total branches+1)/plant = 0.75 + 0.02 (0.002) x Days, R^2=0.59**
Westar $\log_{10}$(total branches+1)/plant = 0.56 + 0.02 (0.004) x Days, R^2=0.42**

Standard error bracketed; **, significant at $P \leq 0.01$; n=28.


Tobin
1986
1985
log10(pods+1) (#/plant)
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
Days
-10
-8
-6
-4
-2
0
2
4
6
8
10


Westar
1986
1985
log10(pods+1) (#/plant)
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
Days
-10
-8
-6
-4
-2
0
2
4
6
8
10


Tobin
1986
1985
log10(total branches+1) (#/plant)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Days
-10
-8
-6
-4
-2
0
2
4
6
8
10

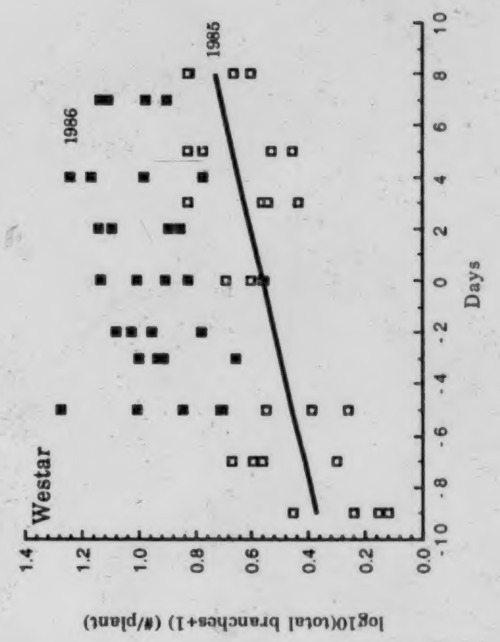

Westar
1986
1985
log10(total branches+1) (#/plant)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Days
-10
-8
-6
-4
-2
0
2
4
6
8
10

Table 11. Standardized partial regression coefficients from stepwise linear regression models on $\log_{10}$(canola seed weight +1) and components of yield on a per plant basis.

			Components of yield					
Year	Cultivar	Step[†]	$\log_{10}$(pods+1) (#/plant)	Seeds/ pod (#)	1000-seed weight (g)	$\log_{10}$(total branches+1) (#/plant)	R^2	SE[§]
1985	Tobin	1	0.84				0.88	0.04
		2	0.80	0.50			0.97	0.02
		3	0.88	0.50	0.24		0.99	0.01
		4	0.82	0.50	0.28	0.08	0.99	0.01
	Westar	1	0.89				0.86	0.11
		2	1.02		0.39		0.94	0.07
		3	0.86	0.30	0.41		0.97	0.04
		4	0.61	0.40	0.44	0.25	0.98	0.04
1986	Tobin	1	0.81				0.77	0.07
		2	0.80	0.45			0.94	0.04
		3	0.80	0.50	0.20		0.97	0.03
	Westar	1	0.78				0.64	0.10
		2	0.72	0.60			0.91	0.05
		3	0.70	0.58	0.21		0.97	0.03

[†] Following the model, $Y = a + bX_1 + cX_2 + dX_3 + e\beta X_4$ where Y is the seed yield (g/plant) and X_1, X_2, X_3, X_4 are components of seed yield, n=28.

[§] SE, square root of the error mean square.

the canola plants were under stress from both the barley and a low moisture regime (Appendix 3). This may partially explain why there was a good relationship between the time of barley emergence and pods per plant in this year and not in 1986. Pod numbers were the most important component of final seed yield for both canola cultivars (Table 11).

Environment has been reported to have little effect on the number of seeds per pod and seed weight (Clarke and Simpson, 1978b). The number of seeds per pod for Tobin was very consistent across barley treatments and over years (Figure 6). Tobin pods contained an average of 11 seeds. Westar had 19 seeds per pod in 1985 and only 12 seeds per pod in 1986. The difference in seed number was likely partially responsible for the low overall seed yields on this cultivar in 1986. Low seed weight (Figure 6), was a second factor. Tobin seed weight was highest when barley emerged before the crop. In this situation, Tobin was no doubt sink-limited due to low pod numbers.

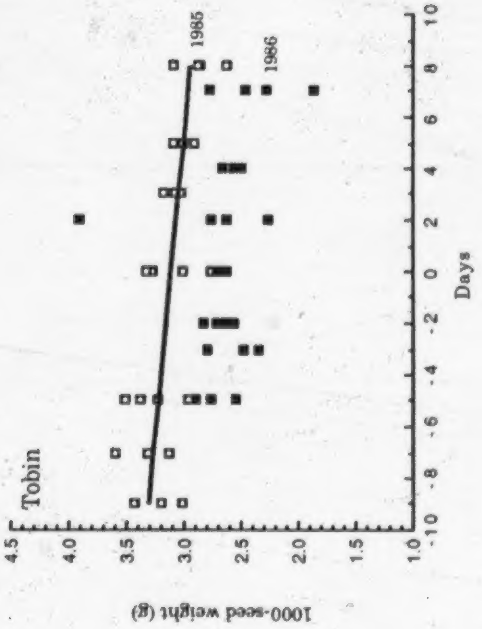
The components of seed yield (branches, pods, seeds per pod and seed weight) accounted for almost all the variability in individual plant seed yield (Appendix 4). Based on the size of the standard partial regression coefficients, pods per plant was the most important component of Tobin and Westar seed yield (Table 11). Pod number was critical to individual plant seed yield and was also the most responsive to competition asserted by barley emerging at different times within the crop. The contribution of seeds per pod to the estimation of seed yield was more important than actual seed weight in Tobin. Tobin yield would be enhanced to a greater extent by having the same number of pods with more seeds or more pods with the same number of seeds rather than greater overall individual seed size. Seeds per pod and seed weight were equally important to Westar seed yield in 1985. In 1986, Westar yielded poorly on an area basis. The per plant data indicated that seeds per pod were more than twice as important in predicting seed yield as 1000-seed weight. This was understandable, considering there were approximately eight fewer seeds per pod in 1986 than in 1985.

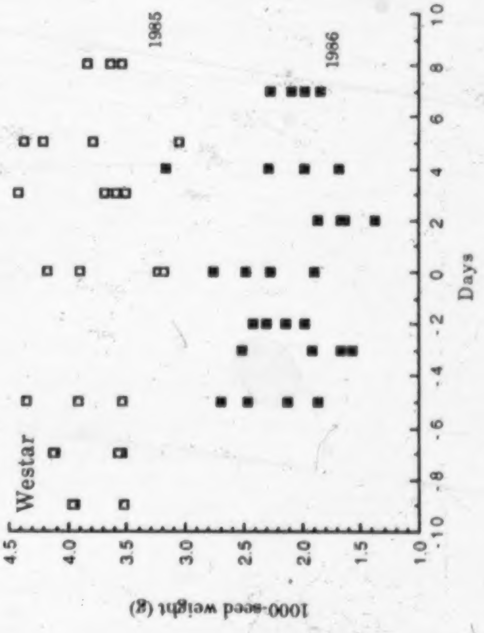
While delayed barley emergence relative to the crop resulted in increased canola seed yields, there were concomitant reductions in barley seed yield (Figure 1). As was the case with canola, time of barley emergence was generally the most important factor included in the barley seed yield stepwise regression equations (Table 12). Although there were no significant differences in the canola plant stand between the treatments, barley seed yield responded to the slight differences in canola and barley stand count.

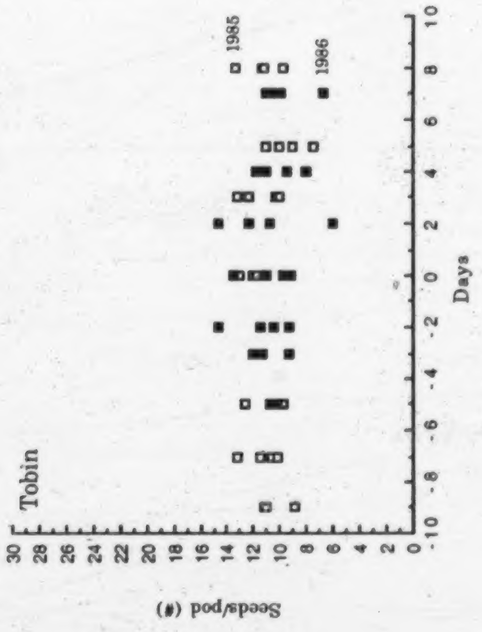
Figure 6. Relationship between seeds per pod and 1000-seed weight, and time of barley emergence for canola grown in 1985 (open symbols) and 1986 (closed symbols).

1985
Tobin 1000-seed weight = 3.11 - 0.02 (0.005) x Days, R^2=0.35**

Standard error bracketed; ** significant at P≤0.01 n=28.


Tobin
1985
1986
1000-seed weight (g)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
Days
-10
-8
-6
-4
-2
0
2
4
6
8
10


Westar
1985
1986
1000-seed weight (g)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
Days
-10
-8
-6
-4
-2
0
2
4
6
8
10


Tobin
1985
1986
Seeds/pod (#)
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
Days
-10
-8
-6
-4
-2
0
2
4
6
8
10

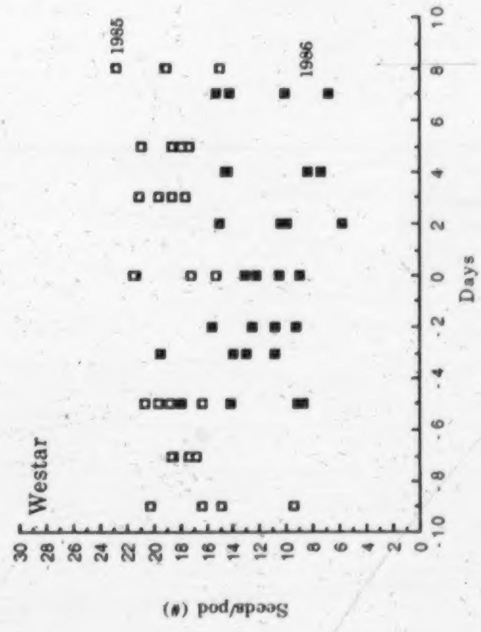

Westar
1985
1986
Seeds/pod (#)
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
Days
-10
-8
-6
-4
-2
0
2
4
6
8
10

Table 12. Relationship between barley seed yield and time of barley emergence, canola emergence count and barley emergence count.

Year	Treatment	Regression coefficients[†]				R^2	Significance[§]
		a	*b*	*c*	*d*		
1985	Barley in Tobin	292.79	-7.22 (1.48)[¥]	-1.69 (0.36)	1.37 (0.75)	0.66	**
	Barley in Westar	162.72	-9.30 (1.30)	-0.87 (0.36)	2.10 (0.53)	0.75	**
1986	Barley in Tobin	-312.19	-19.88 (2.499	-	8.76 (2.55)	0.69	**
	Barley in Westar	188.57	-19.97 (4.54)	-	-	0.47	**

Standard partial regression coefficients

Year	Cultivar	Days	Crop emergence count	Barley emergence count
1985	Barley in Tobin	-0.59	-0.56	0.22
	Barley in Westar	-0.85	-0.29	0.41
1986	Barley in Tobin	-1.23	-	0.41
	Barley in Westar	-1.10	-	-

[†] Following the model, $Y = a + bD + cC + dB$ where Y is the seed yield (g/m^2); D, days barley emerged before or after the crop; C, crop emergence count (#/m^2); B, barley emergence count (#/m^2), n=28

[§] **, significant at $P \leq 0.01$.

[¥] Standard error bracketed.

Barley culm count is related to overall seed yield. Time of barley emergence had a direct effect on the number of barley seed-bearing tillers present at harvest. Culm counts/m^2 were highest in the earliest emerging barley and declined through the later emergence dates (Figure 7). There was no difference in the number of culms/m^2 present for barley grown in Tobin or Westar canola. There was, however, a difference in the basic number of culms present in the two years. Based on the equations that were developed (Table 13), there were approximately 195 culms/m^2 in barley emerging nine days before Tobin or Westar in 1985. The culm count was reduced by three for each day barley emergence was delayed in the crop. In 1986, there were approximately 241 culms/m^2 in barley emerging five days before the canola crop. There was an 11 culms/m^2/day reduction as the time of barley emergence was delayed.

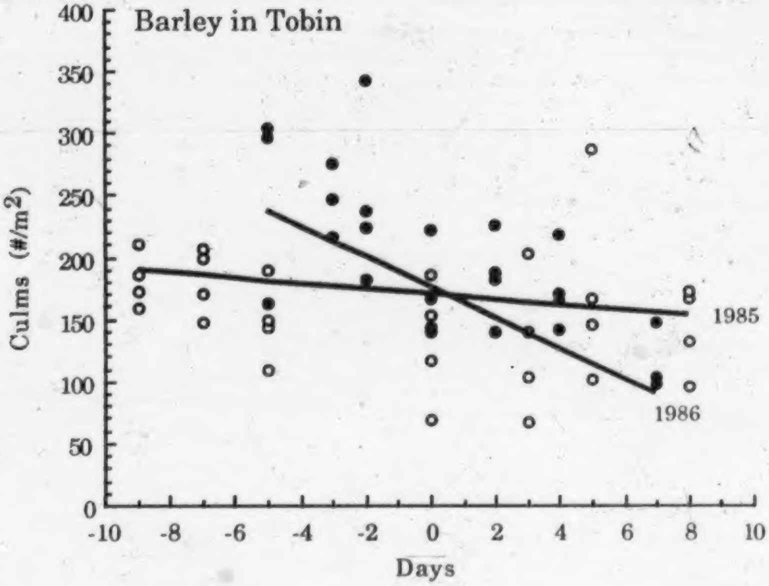
Time of barley emergence was generally the main factor that determined culm count. However, the canola and barley plant numbers also accounted for a portion of the culm count variability in three of the four regression equations (Table 13). Barley stand had a positive effect on culm count while late barley emergence and increased canola stand count reduced the number of barley culms present at harvest.

While harvest indices were largely unchanged by the timing of barley emergence, the harvest indices of barley declined as barley emerged later with respect to the canola (Figure 2). Based on the regression equations developed (Table 14), barley grown in Westar had harvest indices that were approximately seven percent higher than barley grown in Tobin at each emergence interval in 1985. Although a greater proportion of dry matter was partitioned into barley grain when the barley grew in Westar, the barley produced less shoot dry matter when grown in this cultivar. As a result of this compensation, barley yields were similar for barley grown in the two canola cultivars.

The 250-kernel weights of the barley growing in canola also declined the later the barley emerged in the canola crop (Figure 3). There were large differences in barley seed size in 1985 and 1986. The barley seed produced in 1985 weighed approximately 2g per 250 kernels more than that grown in 1986. In 1985, there were also differences in the seed size of barley grown in the two canola cultivars. The seed of barley grown in Tobin was largest when the barley emerged four days prior to Tobin. It was highest for the earliest time of barley emergence (-9 days) in Westar (based on the equations in Table 15). The individual barley seeds were smaller the later the barley emerged.

Figure 7. Relationship between culm count and time of barley emergence for barley grown with canola in 1985 (open symbols) and 1986 (closed symbols).

Lines predicted from regression equations assume a mean crop density of 98 plants/m^2 and a mean barley density of 62 plants/m^2.


Barley in Tobin
400
350
300
250
200
150
100
50
0
Culms (#/m2)
-10
-8
-6
-4
-2
0
2
4
6
8
10
Days
1985
1986

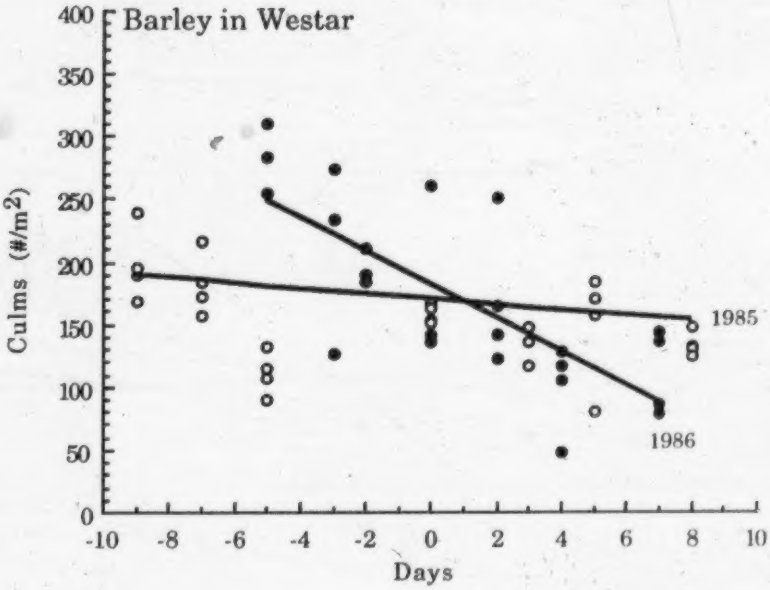

Barley in Westar
400
350
300
250
200
150
100
50
0
Culms (#/m2)
-10
-8
-6
-4
-2
0
2
4
6
8
10
Days
1985
1986

Table 13. Relationship between barley culm count and time of barley emergence, canola emergence count and barley emergence count.

Year	Treatment	Regression coefficients[†]				R^2	Significance[§]
		a	*b*	*c*	*d*		
1985	Barley in Tobin	223.41	-2.12 (0.94)[Y]	-1.37 (0.23)	1.30 (0.48)	0.70	**
	Barley in Westar	159.50	-4.02 (0.83)	-0.90 (0.23)	1.48 (0.33)	0.66	**
1986	Barley in Tobin	-7.40	-12.36 (1.89)	-1.43 (0.89)	5.22 (1.66)	0.70	**
	Barley in Westar	181.44	-13.37 (2.42)	-	-	0.56	**

Standard partial regression coefficients

Year	Cultivar	Days	Crop emergence count	Barley emergence count
1985	Barley in Tobin	-0.27	-0.71	0.33
	Barley in Westar	-0.68	-0.55	0.53
1986	Barley in Tobin	-1.21	-0.20	0.38
	Barley in Westar	-1.17	-	-

[†] Following the model, $Y = a + bD + cC + dB$ where Y is the seed yield (g/m^2); D, days barley emerged before or after the crop; C, crop emergence count ($\#/m^2$); B, barley emergence count ($\#/m^2$), n=28.

[§] **, significant at $P \leq 0.01$.

[Y] Standard error bracketed, n=28.

Table 14. Relationship between barley harvest index and time of barley emergence, canola emergence count and barley emergence count.

		Regression coefficients[†]			
Year	Treatment	*a*	*b*	R^2	Significance[§]
1985	Barley in Tobin	49.12	-0.33 (0.10)[¥]	0.29	**
	Barley in Westar	55.99	-0.28 (0.06)	0.42	**
1986	Barley in Tobin	41.23	-0.69 (0.27)	0.21	*
	Barley in Westar	36.34	-1.14 (0.37)	0.30	**

[†] Following the model, $Y = a + bD$ where Y is the harvest index (%); D, days barley emerged before or after the crop, n=28.

[§] **, significant at $P \leq 0.01$; *, significant at $P \leq 0.05$.

[¥] Standard error bracketed.

Table 15. Relationship between barley 250-kernel weight and time of barley emergence and barley emergence count, Experiment 4.

		Regression coefficients				
Year	Treatment	*a*	*b*	*c*	R^2	Significance[†]
1985	Barley in Tobin	10.50	-0.042 (0.016)[¥]	-0.006[Ω] (0.003)	0.24	*
	Barley in Westar	9.70	-0.034 (0.013)	-	0.20	*
1986	Barley in Tobin	7.82	-0.117 (0.027)	-	0.42	**
	Barley in Westar	4.84	-0.085 (0.022)	0.036[ℵ] (0.021)	0.33	**

Standard partial regression coefficients

Year	Treatment	Days	Days^2	Barley emergence count
1985	Barley in Tobin	-0.47	-0.33	-
	Barley in Westar	-0.44	-	-
1986	Barley in Tobin	-1.39	-	-
	Barley in Westar	-0.71	-	0.30

[†] Following the model, $Y = a + bD + cD^2$ or B where Y = barley 250-kernel weight (g); D, days barley emerged before or after the crop; D^2, days squared; B, barley emergence count ($\#/m^2$), n=28.

[§] **, significant at $P \leq 0.01$; *, significant at $P \leq 0.05$.

[¥] Standard error bracketed.

[Ω] D^2 used in this equation.

[ℵ] B used in this equation.

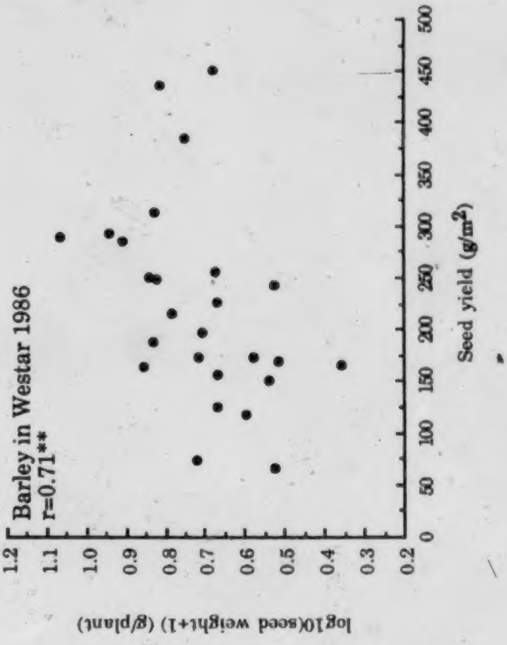
Barley seed yield on an area basis and barley seed yield on a per plant basis $\log_{10}$(seed yield+1) were significantly and positively correlated (Figure 8). The number of spikes per plant present at harvest declined as the barley emerged later with respect to the canola crop in 1986 (Figure 9). This same response was not evident on a per plant basis in 1985 although it had been apparent for barley culms an area basis. The number of nodes per rachis was variable (Figure 9). There were more nodes per rachis in 1986 than in 1985. In general, there were fewer rachis nodes when barley emerged eight days after the crop than when to barley emerged six or nine days before the canola crop. The time of barley emergence relative to the canola crop had no effect on the number of seeds per node (Figure 10). Once a node was developed it generally had three seeds. Barley emerging after the canola had smaller seeds than barley emerging before the canola (Figure 10).

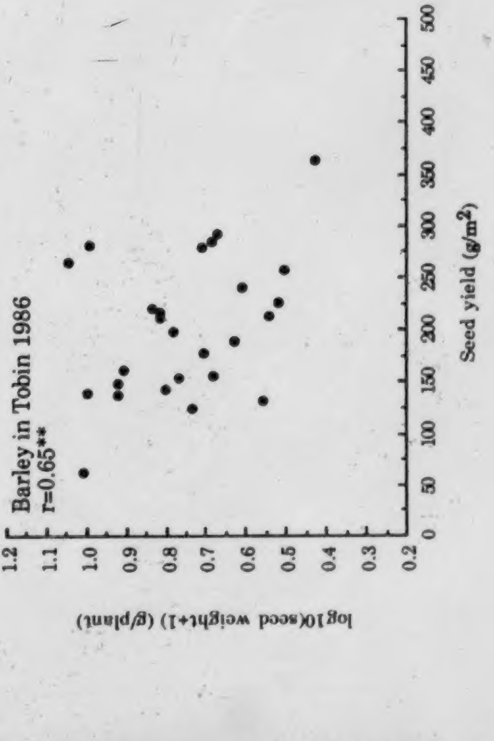
The number of spikes per plant was the most important component of barley seed yield on a per plant basis as determined by the size of the standardized partial regression coefficients (Table 16) from the stepwise linear regression equations that were developed (Appendix 5). The number of spikes per plant accounted for 49% or more of the variability in barley seed yield.

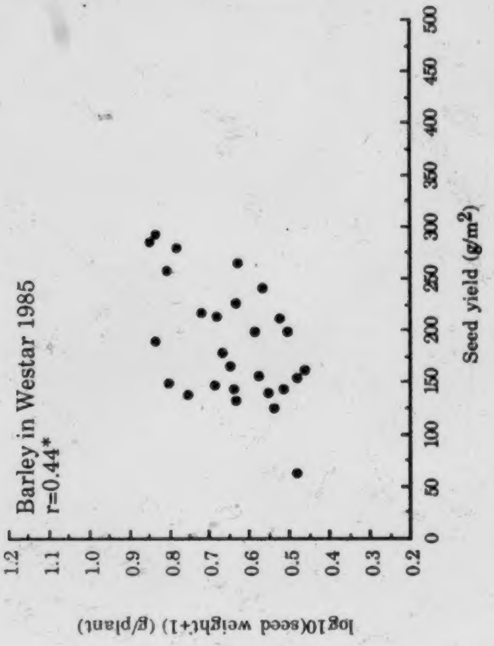
While potential tiller number is a genotypic characteristic, environmental factors such as water status and plant density have a tremendous effect on the number of tillers a barley plant will actually develop (Wych *et al.*, 1985). Tillers and spikes are initiated before stem elongation, and any environmental stress at this time would be evident later in the number of spikes per plant or rachis nodes. It was clear that barley development at the sensitive periods of tiller and spike initiation was affected by canola. The number of spike-bearing culms/m^2 at final harvest declined when barley emergence was delayed (Figure 9). On a per plant basis, the relationship was the same as that observed on an area basis in 1986 but it was unclear in 1985. This may have been due to moisture stress limiting tiller number to a larger extent than stress exerted by the canola plants emerging before the barley. The effect of time of barley emergence in canola on the number of nodes per rachis was variable. In this experiment, barley plants that emerged after the crop had fewer nodes per rachis (Figure 9). Combined with fewer spikes, this meant that the potential yield of the late emerging barley was limited prior to anthesis.

A second phase of barley development that occurs prior to anthesis is one in which the spikes and stems are growing rapidly. Barley stems serve as a source of

Figure 8. Correlation between barley seed yield and mean barley seed yield of the five-plant harvest sub-sample for barley grown with canola in 1985 and 1986.


Barley in Westar 1986
r=0.71**
log10(seed weight+1) (g/plant)
Seed yield (g/m^2)
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
50
100
150
200
250
300
350
400
450
500


Barley in Tobin 1986
r=0.65**
log10(seed weight+1) (g/plant)
Seed yield (g/m^2)
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
50
100
150
200
250
300
350
400
450
500


Barley in Westar 1985
r=0.44*
log10(seed weight+1) (g/plant)
Seed yield (g/m^2)
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
50
100
150
200
250
300
350
400
450
500

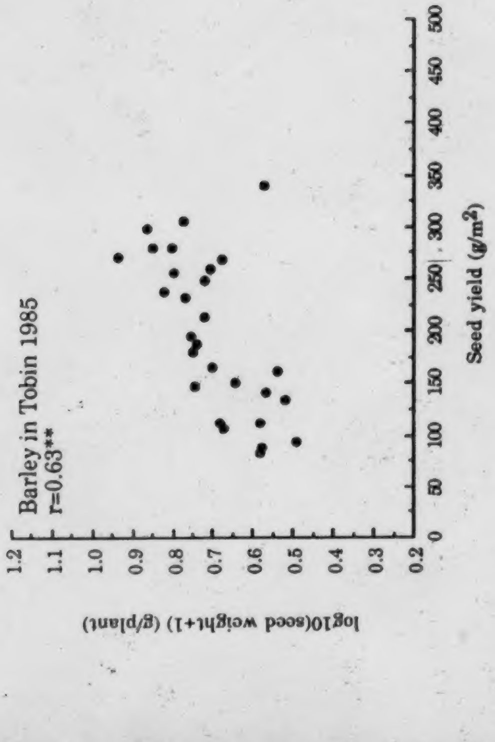
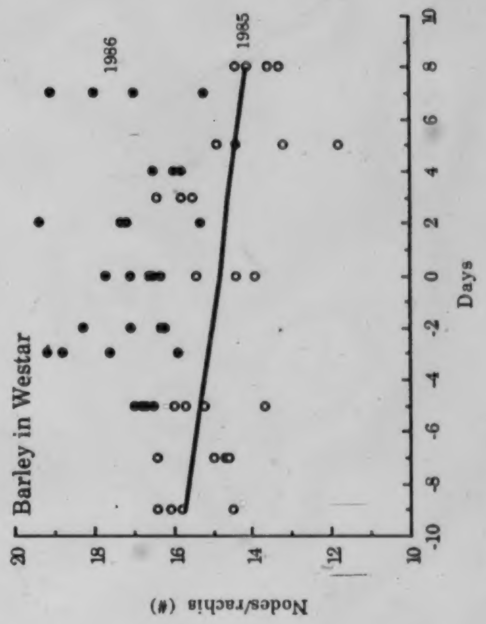

Barley in Tobin 1985
r=0.63**
log10(seed weight+1) (g/plant)
Seed yield (g/m^2)
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
50
100
150
200
250
300
350
400
450
500

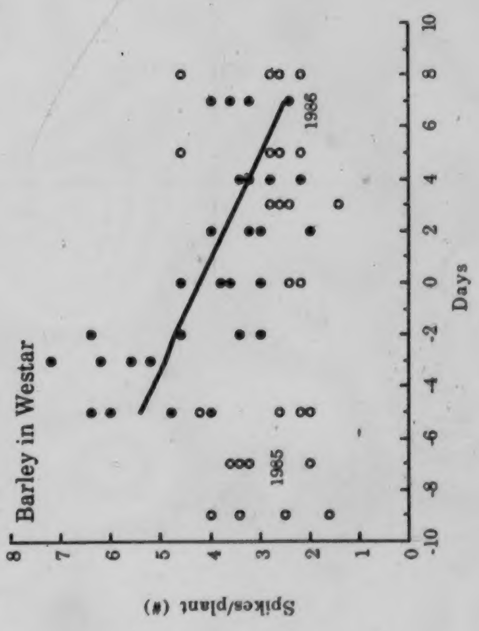
Figure 9. Relationship between spikes per plant and nodes per rachis, and time of barley emergence for barley grown in canola, 1985 (open symbols) and 1986 (closed symbols).

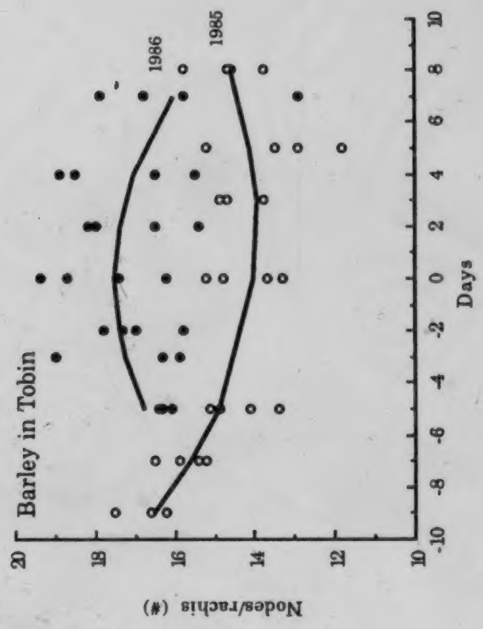
1985
Barley in Tobin nodes/spike = 14.03 - 0.09 (0.03) x Days + 0.02 (0.007) x Days^2, R^2=0.51**
Barley in Westar nodes/spike = 14.89 - 0.09 (0.03) x Days, R^2=0.23*

1986
Barley in Tobin spikes/plant = 4.24- q 0.19 (0.07) x Days, R^2=0.24*
Barley in Westar spikes/plant = 4.20 - 0.24 (0.05) x Days, R^2=0.44**
Barley in Tobin nodes/spike = 17.50 - 0.03 (0.02) x Days^2, R^2=0.15*

Standard error bracketed; **, significant at $P \leq 0.01$; *, significant at $P \leq 0.05$; n=28.


Barley in Westar
Nodes/rachis (#)
20
18
16
14
12
10
Days
-10
-8
-6
-4
-2
0
2
4
6
8
10
1986
1985


Barley in Westar
Spikes/plant (#)
8
7
6
5
4
3
2
1
0
Days
-10
-8
-6
-4
-2
0
2
4
6
8
10
1986
1985


Barley in Tobin
Nodes/rachis (#)
20
18
16
14
12
10
Days
-10
-8
-6
-4
-2
0
2
4
6
8
10
1986
1985

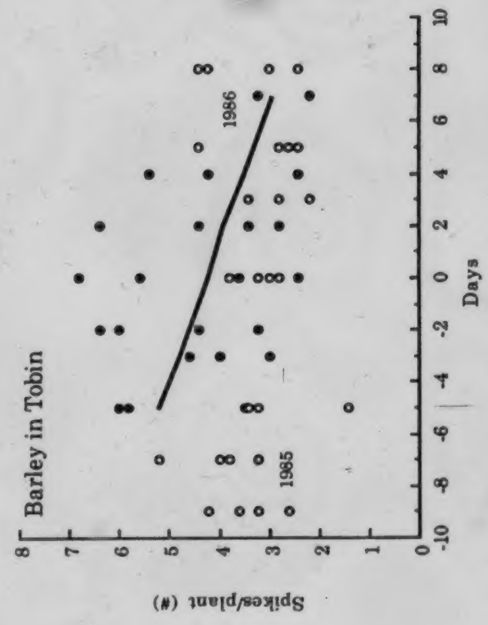
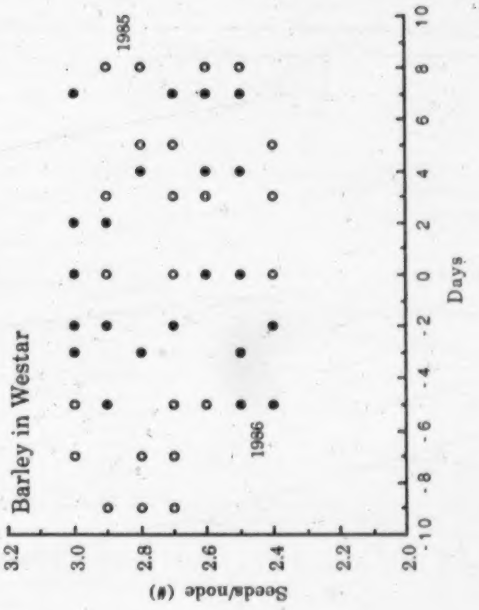

Barley in Tobin
Spikes/plant (#)
8
7
6
5
4
3
2
1
0
Days
-10
-8
-6
-4
-2
0
2
4
6
8
10
1986
1985

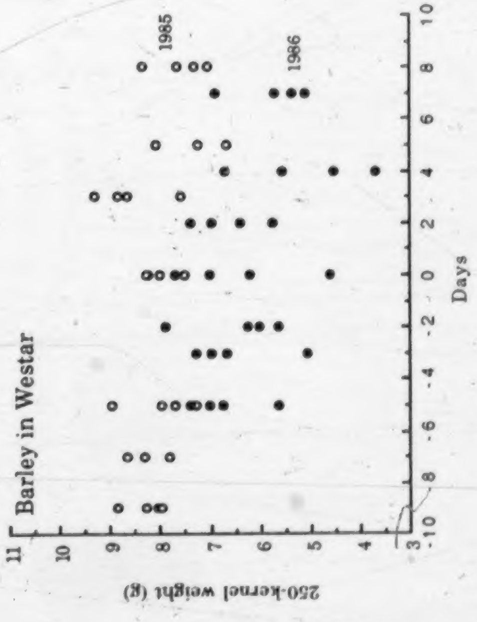
Figure 10. Relationship between seeds per node and 250-kernel weight, and time of barley emergence for barley grown with canola in 1985 (open symbols) and 1986 (closed symbols).

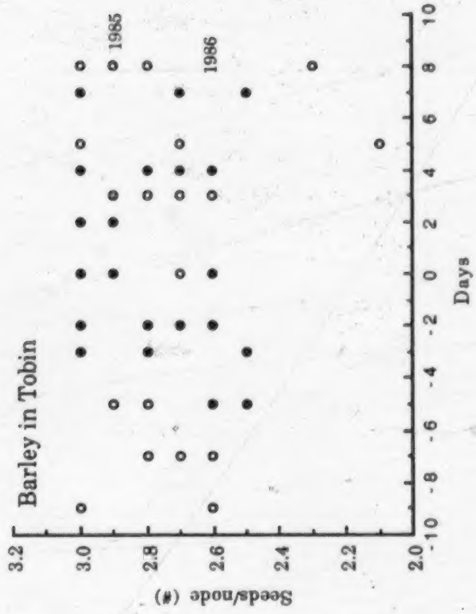
1985

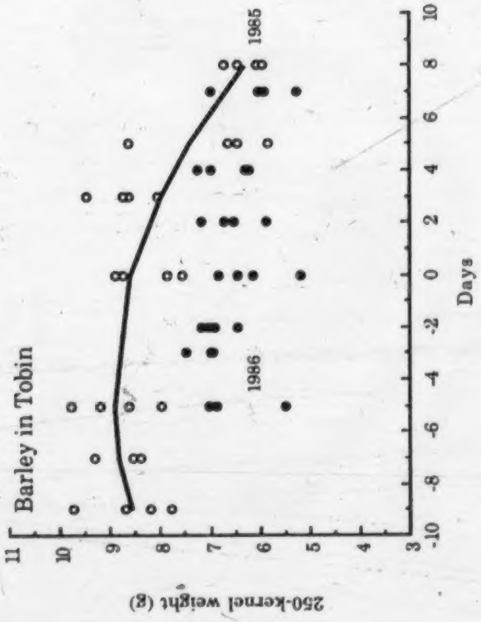
Barley in Tobin 250-kernel weight = 8.58 - 0.15 (0.03) x Days - 0.02 (0.005) x Days^2, R^2=0.58**

Standard error bracketed; **, significant at $P \leq 0.01$; n=28.


Barley in Westar
Seeds/node (#)
3.2
3.0
2.8
2.6
2.4
2.2
2.0
-10
-8
-6
-4
-2
0
2
4
6
8
10
Days
1985
1986


Barley in Westar
250-kernel weight (g)
11
10
9
8
7
6
5
4
3
-10
-8
-6
-4
-2
0
2
4
6
8
10
Days
1985
1986


Barley in Tobin
Seeds/node (#)
3.2
3.0
2.8
2.6
2.4
2.2
2.0
-10
-8
-6
-4
-2
0
2
4
6
8
10
Days
1985
1986


Barley in Tobin
250-kernel weight (g)
11
10
9
8
7
6
5
4
3
-10
-8
-6
-4
-2
0
2
4
6
8
10
Days
1985
1986

carbohydrate and nitrogen that is mobilized and translocated to kernels during grain filling. It is estimated that 11 to 44% of the assimilate produced before anthesis is moved into the grain (Wych *et al.*, 1985). Therefore, a reduction in dry matter production due to the presence of canola at this time will also have an effect on the final grain yield. The earliest emerging barley plants were larger than those that emerged after the canola (Tables 6 and 8), so they had the potential for higher yield based on the ability to produce and store photoassimilate.

The final phase of barley development is comprised of anthesis, grain growth and maturation. The number of seeds per node is a component determined at anthesis. The success of fertilization is likely to be more sensitive to climatic stresses such as temperature or moisture affecting pollen viability than to environmental factors such as plant density (Evans *et al.*, 1975). Seed survival and size are dependent on assimilate supply (Langer, 1967) which could be affected by other plants. There was no indication that seed set was altered by the time at which barley emerged in the crop in this experiment. Most spikelets carried their full complement of seeds until harvest (Figure 10).

Kernel weight is a relatively stable component of barley yield. This has been attributed to the ability of the barley plant to mobilize assimilates from the stem (Wych *et al.*, 1985). It has been estimated that 60% of the carbohydrate in kernels comes directly from spike photosynthesis (Langer, 1967). Canola that shades barley during this filling phase has the ability to limit barley kernel filling by reducing the spike photosynthetic rate. The time at which barley emerged in the crop affected barley kernel size (Figures 3 and 10). The kernels of late emerging barley were smaller than those of barley that emerged before the crop. It appeared that the kernels of barley grown in Tobin were larger than those of barley grown in Westar. This suggests that the retention of leaf area by this cultivar was instrumental in limiting barley filling by shading.

Of the components of barley seed yield, spikes per plant was the most influential in determining seed yield of individual plants (Table 16). This yield component is determined early in the barley developmental cycle so that canola plants that develop rapidly (such as Tobin) might have a better chance of limiting barley yield by inhibiting tiller development or increasing tiller senescence. Limiting the overall production of dry matter prior to anthesis appeared to have a smaller effect on barley yield than on canola yield. Rather than using this dry matter as a basis for pod

Table 16. Standardized partial regression coefficients from stepwise linear regression models on $\log_{10}$(barley seed weight+1) and components of yield on a per plant basis.

Year	Treatment	Step[†]	Components of yield: Spikes/ plant (#)	Nodes/ rachis (#)	Seeds/ node (#)	250-kernel weight (g)	R^2	SE[§]
1985	Barley in Tobin	1	0.75				0.49	0.08
		2	0.81			0.53	0.81	0.05
		3	0.91		0.45	0.52	0.92	0.03
		4	0.85	0.39	0.39	0.48	0.98	0.02
	Barley in Westar	1	0.89				0.74	0.06
		2	0.91	0.54			0.92	0.04
		3	0.90	0.51	0.21		0.94	0.03
		4	0.88	0.29	0.32	0.27	0.97	0.02
1986	Barley in Tobin	1	0.99				0.87	0.06
		2	0.86	0.31			0.92	0.05
		3	0.82	0.32	0.25		0.96	0.04
		4	0.82	0.26	0.24	0.27	0.99	0.04
	Barley in Westar	1	0.87				0.70	0.09
		2	0.72			0.48	0.94	0.04
		3	0.77		0.24	0.37	0.96	0.03
		4	0.74	0.23	0.26	0.36	0.99	0.02

[†] Following the model, $Y = a + bX_1 + cX_2 + dX_3 + eX_4$ where Y is the seed yield ($\log_{10}$ (seed yield+1)g/plant) and X_1, X_2, X_3, X_4 are components of seed yield, n=28.

[§] SE, square root of the error mean square.

production, as occurred in canola, barley potential seed yield had already been set. The effect of assimilate stored during stem development that is available for transport to the barley grain after anthesis also had an effect on barley yield. The declining harvest indices that were observed as barley emergence was delayed (Figure 2) meant that a smaller proportion of the dry matter produced ended up in the seed. A large proportion of the total plant weight was produced after anthesis. Canola would affect the production of this dry matter if it reduced flag leaf and spike photosynthesis by shading. Canola plants that maintain leaf area (*i.e.* with long leaf area durations, like Westar) could reduce barley seed yield by limiting seed filling as well as having the advantage of deterring late-season weed emergence.

The compensation between the components of canola and barley yield showed the basic differences in the responses of plants with different growth habits to the stress imposed by time of emergence. Barley was to reduced the number of parts formed (tillers). During the vegetative growth phase, canola responded to stress by reducing the size of existing parts. When these plants entered the reproductive phase, pod number rather than size was altered. A similar response was observed by Williams (1964) for a mixture of kale and lamb's-quarters.

Economics. The economic importance of timeliness of barley control in canola with a post-emergence herbicide was determined based on the yield data from the experiment. Canola and barley yields, with respect to time of barley emergence, were derived from regression equations that were developed for individual years (Tables 10 and 12). The following assumptions were made.

The value of the canola crop when barley is controlled with a herbicide was:

A = *[Barley-free canola yield* x *Market price] - [Herbicide + Application cost]*

This model assumes that there is no yield loss prior to or after herbicide treatment.

The cash return (seeding, fertilizer and harvesting costs not included) on canola when barley is not controlled, and assumed to have no economic value, was:

B = *[Canola yield at various times of barley emergence* x *Market price]*

The cash return when barley is not controlled, and is considered to have economic value, was:

C =*([Canola yield at various times of barley emergence x Market price] + [Barley yield at various times of barley emergence* x *Market price]) - Separation cost*

The following assumptions were made:

(1) 1985 Barley-free Tobin seed yield= 2.81 t/ha, 1985 barley-free Westar seed yield=2.54 t/ha, 1986 Barley-free Tobin seed yield=2.52 t/ha.

(2) August 28, 1989, Alberta Wheat Pool price at the Lacombe elevator; No. 1 canola, $5.46/bu or $240.51/t; No. 1 barley, $1.77/bu or $81.22/t.

(3) Barley control with the recommended rate of POAST™[9] (sethoxydim[10], 266 g ai/ha) plus ASSIST OIL CONCENTRATE and ammonium sulphate. Lacombe Fertilizer price, August 28, 1989, $47.20/ha.

(4) Herbicide application cost, $6.75/ha. This was the average custom application cost for Region 5 (Lacombe area) in 1988[11] .

(5) The maximum seed separation cost for canola and barley, Bentley Seed Cleaning Co-operative, August 28, 1989, $9.95/t.

The yield potential of the two canola cultivars in 1985 is reflected in the weed-free value of the crop (A) (Figure 11). The value of a crop of Tobin, based on the assumptions, was $65.00/ha more than for Westar because it produced 0.27 t/ha more seed. Tobin also was able to produce more seed than Westar in the presence of barley, regardless of when the barley emerged relative to the crop. This accounts for the differences between the lines that represent the return on canola where the barley is treated as a weed of no economic value (B). When the barley emerged nine days before the canola, Tobin produced 0.18 t/ha more seed than Westar. This accounts for the $42/ha difference in the value of the two cultivars. Tobin yield was also higher than Westar when barley emerged eight days after the crop, which resulted in a $47/ha difference in the return from the two canola cultivars. Even when the value of barley is considered (C) the return from the combined canola and barley yield did not equal the value of the weed-free canola crop. Barley emerging as late as eight days after the canola crop, and left uncontrolled, resulted in yield losses of $54/ha and $36/ha for Tobin and Westar compared to the weed-free crop.

The scenario for Tobin canola in 1986 differed from that in 1985. The value of the weed-free crop was similar in both years, but Tobin yield was lower overall when barley was present. The value of the crop, assuming the barley was worthless, was less than in 1985 because of this lower yield. While the barley yielded 3.2 t/ha when it

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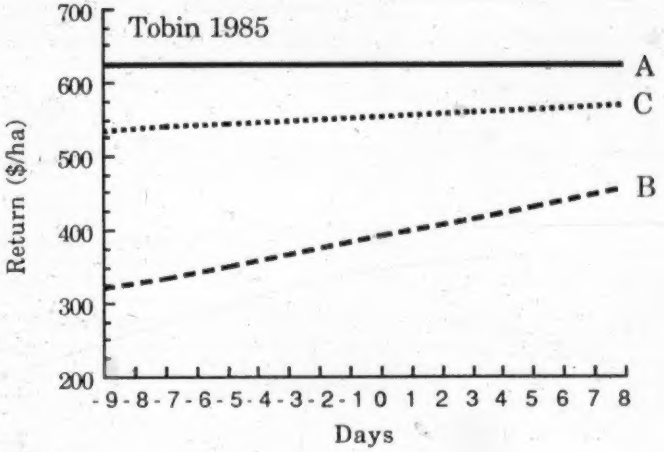
[9] BASF Canada Inc., 1700-521 3 Ave.,S.W., Calgary, Alberta T2P 3T3

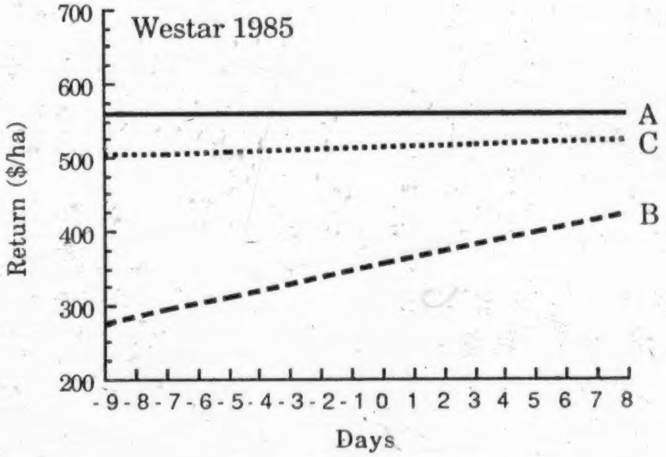
[10] 2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one

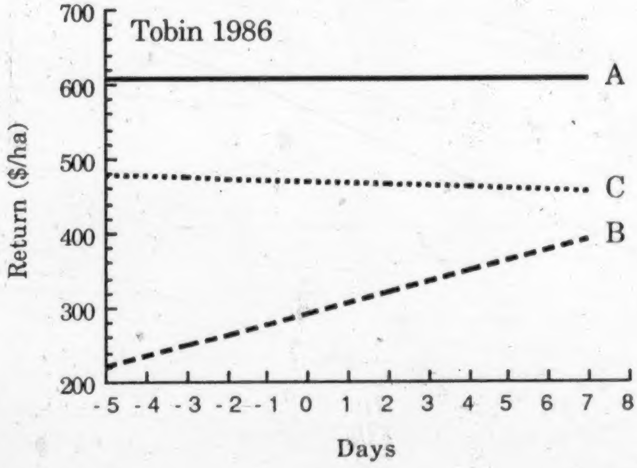
[11] Custom Rates Survey Summary 1989. Agdex No. 825-9. Alberta Agriculture.

Figure 11. Economics of barley control in canola.

Line A is the cash return when barley is controlled with a herbicide. Line B is the cash return when barley is not controlled. Line C is the cash return when barley is not controlled but considered to have an economic value.


Tobin 1985
Return ($/ha)
700
600
500
400
300
200
A
C
B
-9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8
Days


Westar 1985
Return ($/ha)
700
600
500
400
300
200
A
C
B
-9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8
Days


Tobin 1986
Return ($/ha)
700
600
500
400
300
200
A
C
B
-5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8
Days

emerged six days before the Tobin, it only yielded 0.9 t/ha when it emerged eight days after the crop. Combined with the lower Tobin yields this resulted in a decline in return when barley emerged after the crop. The dollar return for uncontrolled barley and Tobin canola in 1986 was much less than in 1985. It is clear that it does not pay to leave a moderately high density of barley (62 plants/m^2) in canola even if it has emerged eight days after the crop. This is not inconsistent with the observation made in Chapter 3, where it was shown that barley control in Tobin was economical if the barley density was 57 plants/m^2 or larger. As Westar yield was limited in 1986, these results will not be discussed.

It was apparent that barley (at the population density used) had exerted a larger effect on final canola seed yield than canola had on barley seed yield. If the two crops had influenced each other's seed yield equally, they would have had similar yields when they emerged simultaneously (*i.e.* time 0). It was not until barley emerged five days after the canola crop that the canola and barley seed yield were equal. This yield relationship combined with the low price of barley, compared to the canola, explains why the value of the two crops combined never equalled the value of weed-free canola. As barley emerged later, canola yield increased, but it did not increase at the same rate as barley yield was reduced. Even though the price of the crop was high, it did not compensate for the overall reduction in canola yield due to the barley. The economics would change if the relationship between the value of the two commodities were to change.

A canola cultivar more adapted to growth in a mixture might make leaving a relatively high density of barley in a canola crop economical. With the two cultivars used in this experiment, it was evident that it paid to apply a post-emergence herbicide to control volunteer barley growth even if the barley had emerged eight days after the crop. It is unlikely that the return on uncontrolled barley and canola would equal that of weed-free canola until the barley emerged at least 40 days after the crop. This would mean that the barley would be emerging into a canola crop that had bolted and was flowering.

SUMMARY

Reduced canola dry weight was a major effect of barley emerging at different times within the canola crop. This was particularly important as dry weight measured during the growing season was also highly correlated with seed yield in both canola and barley. Dry matter limitation was reflected differently in the two genera. Canola exhibited a combined indeterminate and determinate growth response. Initially, vegetative size of the plant was reduced, then pod number was affected once the plants moved into the reproductive growth phase. Barley exhibited a typical determinate growth pattern by reducing the number of parts, specifically tillers. Pod number and tiller number were the two components critical to canola and barley seed yield, respectively. The cumulative effect on plant development when canola and barley were grown together was important. Canola dry weight was generally not affected by the time of barley emergence, but pod production was limited when barley emerged before the crop, and tiller production was reduced when barley emerged after the canola. The effect of time of barley emergence on yield components was ultimately reflected in final seed yield.

Canola yield was reduced between 70 and 160 kg/ha for each day barley emerged before the crop. The difference in yield potential of the two canola cultivars was seen in final seed yield. Tobin (*B. campestris*) developed more rapidly than Westar (*B. napus*). This is an advantage in a short-season environment, such as at Lacombe, as seed filling can be limited by fall frost. The rate of development of Tobin would give it a competitive edge early in the season. However, the maintenance of leaf area well into August would allow Westar to effectively shade late emerging weeds. With respect to the barley, the results suggested that Tobin was more effective at reducing growth of barley that emerged before the crop while Westar was better at limiting growth of barley that emerged after the crop.

Post-emergence herbicide application would be cost-effective when moderate densities of barley emerge between nine days before and eight days after a canola crop. The balance between the canola and barley seed yield and commodity prices was such that the seed obtained at the density of barley used in the experiment did not balance the value of the canola yield lost.

CHAPTER 5

COMPETITION BETWEEN CANOLA AND BARLEY: EFFECT OF DURATION OF BARLEY COMPETITION ON THE CANOLA CROP

INTRODUCTION

Timing of weed control measures is almost as important as the actual removal of the weed from a crop. Timeliness of weed control is essential for herbicide efficacy and to limit potential yield loss due to weed competition. The critical period or duration is the time a weed may be present without causing yield loss. Determination of the length of this period makes it possible for producers to apply herbicides before measurable crop loss, attributable to weed competition, occurs.

Critical periods vary with the crop grown, weed type and density, and environmental conditions. The time (duration of competition) variable alone accounted for 0.4 to 1.1% per day of the yield loss attributable to Tartary buckwheat (*Fagopyrum tataricum* (L.) Gaertn.) grown in several crops at Lacombe, Alberta (de St. Remy and O'Sullivan, 1986). Weed and crop density also had some effect on the yield reduction. Of the five crops evaluated, rapeseed (*Brassica campestris* L.) was the most competitive with Tartary buckwheat. After 70 days of Tartary buckwheat competition, rapeseed yield loss was 20%. Rapeseed yield loss due to season-long competition at the same density of wild oats (*Avena fatua* L.) (75 plants/m^2) in a similar environment would be 28% (Dew and Keys, 1976).

There are few reports on the effect of duration of weed competition on rapeseed/canola yield. No reports on time of barley removal from rapeseed/canola barley competition originating in North America are known to the author. Garcia Torres and Vasquez Cobo (1981) seeded spring-type rapeseed (*B. napus* L.) in November and harvested the crop in May in the Andalusian region of Spain. Rapeseed yield loss due to season-long competition from a variety of weeds averaged 28% for 12 experiments. Weed-crop competition for 6, 10 or 12 weeks after emergence reduced crop yield by 13, 25 and 32% respectively.

British results on the effect of volunteer cereal competition on winter rapeseed yield have been less conclusive (Lutman 1984). A mixed weed population (up to 200 plants/m^2) did not generally reduce rapeseed yield. However, volunteer cereals and other annual grasses exceeding 70 plants/m^2 were more competitive than broad-leaved weed species in reducing spring growth of the crop.

In experiments where weeds were removed from the crop at various intervals, there was little evidence that early weed eradication resulted in higher crop yield. Orson (1984) examined the timing of herbicide application for volunteer winter cereal control. When the rapeseed crop was growing vigorously, the time of cereal removal had little effect on final seed yield. However, in one experiment a 21% advantage in yield was observed when winter barley (*Hordeum vulgare* L.) was controlled with fluazifop-butyl[1] at the two to three leaf stage rather than two weeks later at the tillering stage.

The first objective of this research was to determine the relationship between duration of barley competition and canola yield and yield parameters. The second objective was to identify the time at which herbicide application would be most beneficial based on the duration-yield relationships identified.

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[1] (±)-2-[4-[[5-(trifluormethyl)-2-pyridinyl]oxy]phenoxy]propanoic acid

MATERIALS and METHODS

Field procedure. Field experiments were conducted at the Agriculture Canada Research Station, Lacombe, Alberta (52^{0} 28' latitude, 113^{0} 44' longitude) in 1985 and 1986. The plots were established on clean, fallowed Ponoka silt loam soil (26% sand, 34% silt, 40% clay, OM 9%. pH 6.0). The seedbed was prepared by cultivating two or three times in the spring with a vibrashank cultivator, followed by harrowing with a spike-tooth harrow.

Brassica campestris cv Tobin and *B. napus* cv Westar canola-type rapeseed were seeded as the crop and *H. vulgare* cv Galt was used to simulate volunteer barley. The experiment was set out in a split-block design. Individual plots were 1.8 x 2.7 m. Percent seed germination and estimated seed vigour were factored into the seed rates for the canola and barley. Barley was seeded at a target density of 75 plants/m^2. The time of removal treatments were arranged in a randomized design, and constituted the main effects or whole plots of this experiment. The barley was removed from 0.84 m^2 quadrats in the appropriate plots by hand at 7, 14, 21, 28, 35, 42 and 56 days after plant emergence. The area outside the weeded quadrats was also weeded to avoid interference from surrounding barley plants. Weed-free (time 0) and weedy-check plots (competition from plant emergence to harvest) were also included in the experiment. In the sub-plot treatments, Tobin or Westar canola was seeded at a target density of 200 plants/m^2 in strips that were randomized within each of the four replications. The canola and barley were planted to emerge simultaneously, with a double-disk press-type drill, in 23-cm rows. The canola seeds were dressed with VITAVAX RS FLOWABLE ™[2] (carbathiin[3] 1 g ai/kg seed, thiram[4] 2 g ai/kg seed, lindane[5] 15 g ai/kg seed) for flea beetle (*Phyllotreta cruciferae* Goeze, *P. striolata* Fab.) and fungal seedling disease protection prior to planting. In both years, 63 kg/ha monoammonium phosphate (11-51-0) fertilizer was applied with the canola seed.

After plant emergence, a 0.84 m^2 area was selected and marked in each plot. The following data were recorded in each quadrat: canola plant counts at emergence and harvest, barley plant counts at emergence, canola shoot dry weights, seed yield, and 1000-seed weights at harvest. Harvest indices[6] were calculated. The seeding, emergence and harvest dates are listed in Table 1.

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[2] Uniroyal Chemical Ltd., 4-2216 27 Ave. N.E., Calgary, Alberta T2E 7A7

[3] gamma-1,2,3,4,5,6-hexachlorocyclohexane

[4] bis(dimethylthiocarbamoyl)disulfide

[5] 5,6-dihydro-2-methyl-1,4-oxathiin-3-carboxanilide

At maturity, the canola plants were hand-cut approximately 5 cm above ground level and placed in large cotton bags. The samples were dried to constant weight and threshed in a stationary thresher.

Each time when the barley was removed from the canola, growth stage observations were made on both the canola and barley. In 1985, these observations were of a general nature. In 1986, the phenological observations (made on 10 plants) were based on Berkenkamp's (1973) scale for canola and Zadoks' scale (Zadoks *et al.*, 1974) for cereals.

At harvest time, five-plant canola subsamples were selected at random from plants adjacent to the quadrat and harvested with the root intact. Plant heights and pod-bearing branch counts (primary, secondary, tertiary and quarternary) were recorded and the plants were individually wrapped in newspaper. The five plants were then put in a paper bag inside a large cotton sack to dry in an oven at 55 C. The root of each plant in the canola subsample was removed from the shoot. The shoot was weighed, and the pods were removed and counted. For a pod to be included in the pod count it had to have at least one developed seed. The pods containing seeds were weighed, and the seed was harvested by hand threshing. The individual seeds were counted using an electronic seed counter[7] and then weighed. The total numbers of branches, seeds per pod and 1000-seed weights for the individual plants were calculated from the preceding information.

Data analysis. The relationship between canola stem weight and seed yield was best described by simple linear regression analysis. Comparisons between slopes of the regression equations were made following the procedure outlined in Gomez and Gomez (1984, p. 373). Analysis of variance on the yield components showed that there was no year x cultivar or year x duration interaction. Transformation $\log_{10}(x+1)$ was

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[6] Harvest index (%) = $\frac{\text{seed yield}}{\text{shoot weight}} \times 100$

[7] Electronic seed counter, Model 850-2, The Old Mill Company, Savage Industrial Center, Savage, Maryland, USA 20763

Table 1. Dates of seeding, emergence and harvest.

Year	Canola or Barley	Seeding date	Emergence date	Harvest date
1985	Tobin	May 21	May 30	Aug. 19
	Barley in Tobin	May 22	May 30	Aug. 19
	Westar	May 22	May 30	Sept. 28
	Barley in Westar	May 22	May 30	Sept. 28
1986	Tobin	May 20	May 28	Aug. 26
	Barley in Tobin	May 20	May 28	Aug. 26
	Westar	May 20	May 28	Sept. 12
	Barley in Westar	May 20	May 28	Sept. 12

required to normalize the branch, pod and seed number data for the five-plant canola subsamples. Means were separated using Student-Newman-Keul's test.

RESULTS and DISCUSSION

Competition between canola and barley began early in the growing season. Canola dry matter production was affected by barley growing in the crop (Figure 1). The amount of material in the stem declined as the duration of barley competition increased in the canola crop. The two canola cultivars differed in the amount of stem material produced. Westar had more stem dry matter than Tobin in weed-free and removal treatments.

The limitation of dry matter production shortly after plant emergence has implications for seed yield production later in the season. Rood *et al.* (1984) have shown that leaves, stems, and then pods act as major sources of photosynthate during the development of canola reproductive structures and that they do so in proportion to their dry weight at the time of carbon assimilation. Since this is a type of chain reaction, limitations to leaf dry matter production will affect stem production, pod production and ultimately seed yield.

As stem dry matter production was limited in proportion to the time barley remained in the crop, so was seed yield (Figure 2). Yield loss over the time interval of this experiment was approximately 1.3 g/m^2 for each day the barley remained in the crop. By 14 days after plant emergence, based on the combined prediction equation developed, 10% of the potential yield has been lost. If the barley were left for 42 days before removal, there would be a yield reduction of approximately 30%. At 14 days after planting, both canola cultivars were still in the rosette stage with three to five leaves per plant (Table 2). The barley plants were approximately 15 cm tall, with four to five leaves and two tillers. At this time, barley adjacent to canola could have been shading the canola plants for at least part of the day. Up until 42 days after planting both canola cultivars still had the potential to form seed as they were still in the flowering stage. Seed production appeared to be limited by the extent to which leaf and stem dry matter was restricted by the barley competition.

Season-long barley competition (approximately 85 days in Tobin, 114 days in Westar) resulted in a 44% loss in canola yield. This was similar to the predicted yield loss (39%) when barley was removed 56 days after plant emergence. It was evident that between 56 days after planting and harvest the canola crop could not compensate by forming many more pods or producing more seeds. The cultivar Tobin had filled the

Figure 1. Relationship between canola stem weight and duration of barley competition.

WDCK, stem weight after season-long competition from the barley.

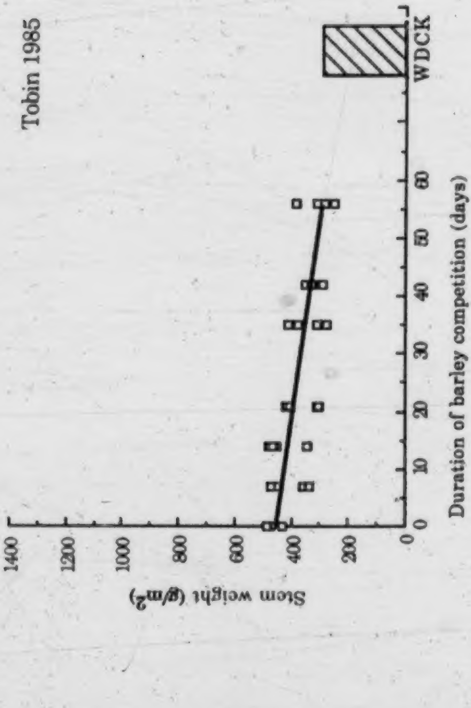
		Regression coefficients[†]		
Year	Cultivar	*a*	*b*	R^2
1985	Tobin	450.01	-2.84 (0.54)[Y]	0.48**[§]
1986	Tobin	802.74	-4.24(0.80)	0.49**
	Westar	1113.46	-5.86(1.38)	0.37**

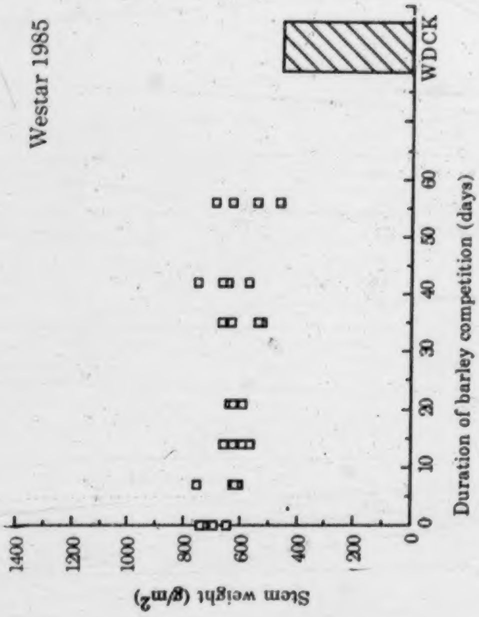
Slope (*b*) comparisons					Significance
Year	Treatment		Year	Treatment	
1985	Tobin	vs	1986	Tobin	**
1985	Tobin	vs	1986	Westar	**
1986	Tobin	vs	1986	Westar	**

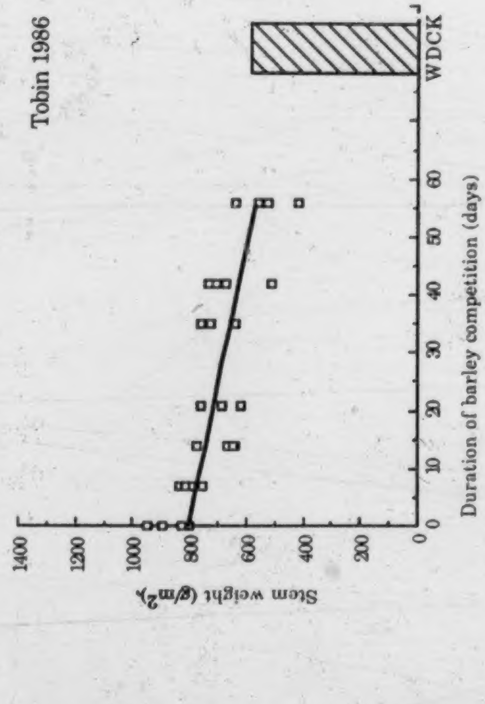
[†] Following the model, $Y=a+bX$ where Y is the canola stem weight (g/m^2) and X is the duration of barley competition (days), n=32.

[§] **, equation significant at $P \leq 0.001$.

[Y] Standard error bracketed.


Tobin 1985
Stem weight (g/m²)
1400
1200
1000
800
600
400
200
0
0
10
20
30
40
50
60
WDCK
Duration of barley competition (days)


Westar 1985
Stem weight (g/m²)
1400
1200
1000
800
600
400
200
0
0
10
20
30
40
50
60
WDCK
Duration of barley competition (days)


Tobin 1986
Stem weight (g/m²)
1400
1200
1000
800
600
400
200
0
0
10
20
30
40
50
60
WDCK
Duration of barley competition (days)

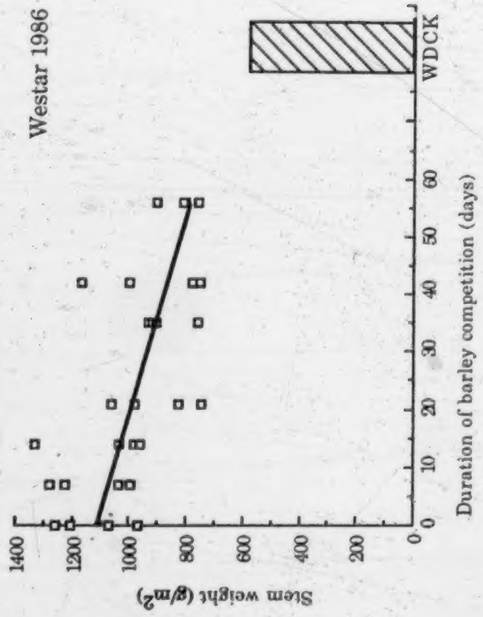

Westar 1986
Stem weight (g/m²)
1400
1200
1000
800
600
400
200
0
0
10
20
30
40
50
60
WDCK
Duration of barley competition (days)

Figure 2. Relationship between canola seed yield and duration of barley competition.

— WDCK, seed yield after season-long competition from the barley.

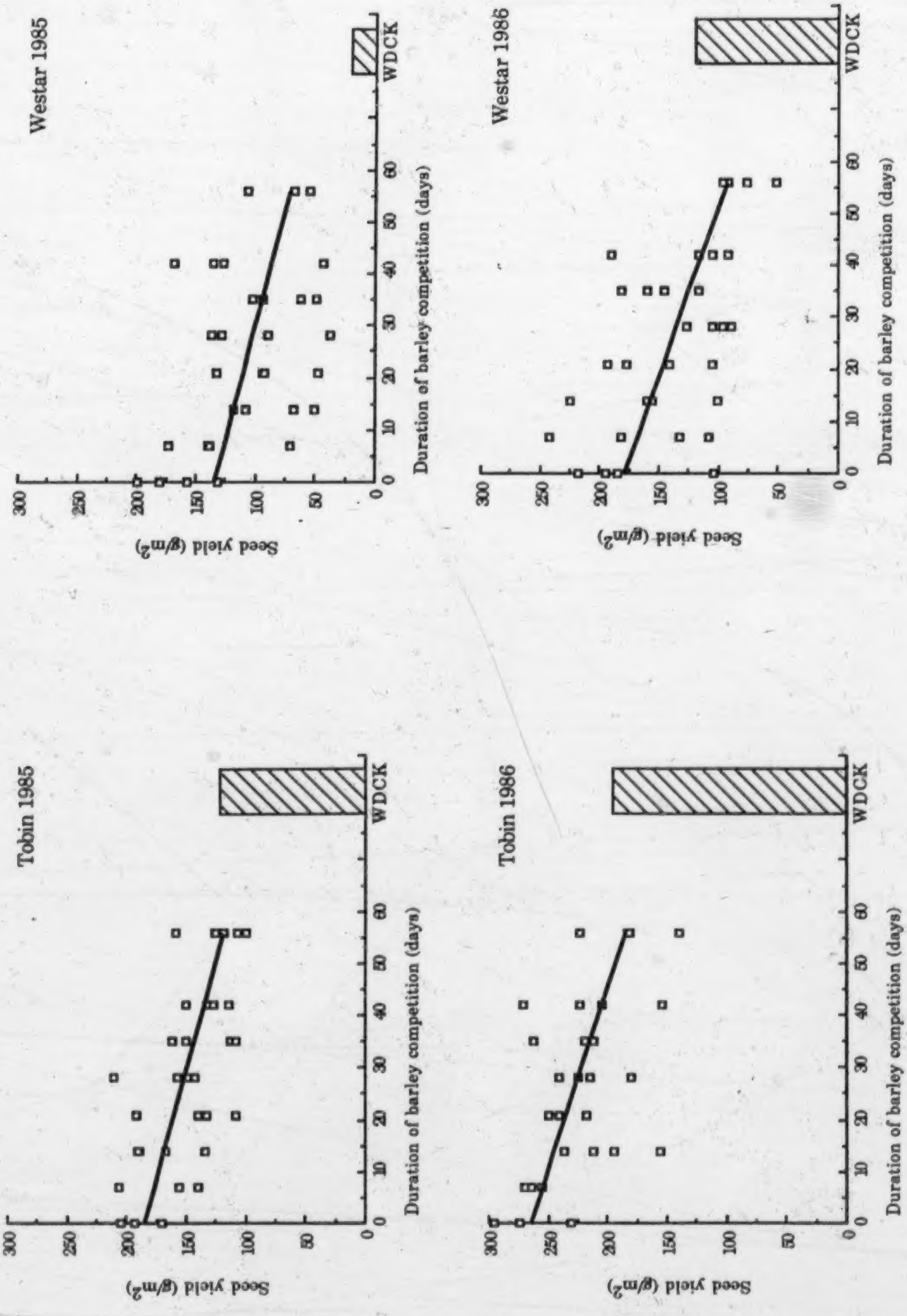
		Regression coefficients[†]		
Year	Cultivar	*a*	*b*	R^2
1985	Tobin	184.74	-1.19 (0.26)[Y]	0.41**[§]
	Westar	134.11	-1.13(0.41)	0.21**
1986	Tobin	264.43	-1.42(0.34)	0.36**
	Westar	178.35	-1.53(0.41)	0.32**
Combined		190.41	-1.32(0.29)	0.14**

Slope (*b*) comparisons					Significance
Year	Treatment		Year	Treatment	
1985	Tobin	vs	1986	Tobin	ns
1985	Westar	vs	1986	Westar	ns
1985	Tobin	vs	1985	Westar	ns
1986	Tobin	vs	1986	Westar	ns

[†] Following the model, Y=*a* + *b*X where Y is the canola seed yield (g/m^2) and X is the duration of barley competition (days), n=32 (combined n=128).

[§] **, equation significant at $P \leq 0.001$; ns, not significant.

[Y] Standard error bracketed.


Westar 1985
Westar 1986
Tobin 1985
Tobin 1986
Seed yield (g/m²)
0
50
100
150
200
250
300
Duration of barley competition (days)
0
10
20
30
40
50
60
WDCK

earliest formed pods by 56 days after planting and had very few unopened flowers remaining. Westar canola, being a later variety, had most of its flower buds open and was filling its lower pods. Once the pods begin to fill, the seeds become progressively stronger sinks for photosynthate because their sink strength is proportional to their dry weight as a percentage of total plant dry weight (Major *et al.* 1984). This means that the potential canola yield becomes fixed as flower and new pod production ceases.

The seed yields of the canola cultivars were similar with respect to the amount of time barley remained in the crop. This was largely due to the differences in dry matter partitioning in the two cultivars which did not vary with the amount of time that the barley remained in the crop. Westar harvest index was 13% in both years while the harvest index of Tobin was 29% in 1985 and 25% in 1986. While Tobin produced less dry matter than Westar, the higher harvest indices meant that it produced equivalent amounts of seed.

What was critical was that by two weeks after plant emergence, at least 10% of the potential canola yield could be lost by not spraying a heavy infestation of barley. Post-emergence herbicides such as fluazifop-butyl and sethoxydim[8] can be used to control volunteer cereals in the two to five-leaf stage and one to six-leaf stage, respectively. This wide 'window of application' may be taken as an indication that the products can be sprayed at any one of these leaf stages without loss of canola yield. The observations made on plant growth stages (Table 2) indicate that the herbicides should be effective up to three weeks after plant emergence. At this time the barley had approximately five leaves and three tillers. The results of these experiments suggest that post-emergence herbicides should be applied as soon as possible after volunteer cereal emergence. Significant yield loss in canola had occurred once barley had passed the three-leaf stage if it emerged at the same time as the canola crop.

The observed reduction in canola yield for the duration of barley competition was greater than that reported by Garcia Torres and Vazquez Cobo (1981) for spring rapeseed grown in Spain. They observed only a 13% reduction in seed yield after six weeks of weed competition. Yield loss appears to be more severe in spring-types of rapeseed/canola with spring barley than in winter rapeseed/canola and winter barley. Lutman (1984) reported that volunteer cereals, exceeding 70 plants/m^2, reduced the spring growth of British winter rapeseed/canola in four trials but in only two cases did

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[8] 2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio) propyl]-3-hydroxy-2-cyclohexen-1-one

Table 2. Stages of the canola and barley growth at the time of weed removal.

Time of removal (days)	Canola growth stage[†]				Barley growth stage	
	Barley absent		Barley present			
	Tobin	Westar	Tobin	Westar	Barley in Tobin	Barley in Westar
7	1.3	1.2	1.3	1.2	13	13
	(1985: Tobin, 1-2 L[§]; Westar, 1 L,; barley, 1.5-2L)					
14	1.5	1.3	1.5	1.3	14	14
					22	22
	(1985: Tobin, 2-3L; Westar, 2-3L; barley, 3-4L)					
21	1.7	1.6	1.7	1.6	15	15
			2.1		23	23
	(1985: Tobin, 7-8L; Westar, 7-8L; barley, 5-6L, 2-4T)					
28	1.9	1.9	1.9	1.7	19	19
	2.4	2.2	3.0		23	23
					34	34
	(1985: Tobin, 10-12L starting to bolt; Westar, 8-10L; barley, 6-7L, 3-4T)					
35	3.1, 3.2	2.3, 2.4	3.1, 3.2	2.3	24	22
					36	36
					43	43
	82 cm	50 cm	81 cm	56 cm	71 cm	78 cm
	(1985: Tobin, all plants bolted most in flower; Westar, 9-12L, not bolted; barley, 8L to shot blade stage, 2-5T)					
42	3.2	3.0	3.2	3.0	22	22
					56	54
	103 cm	97 cm	101 cm	92 cm	88 cm	85 cm
	(1985: Tobin, all plants bolted and flowering, quite a few pods set; Westar, early flower, some plants not bolted; barley, 9L to shot blade stage, 2-3T)					
49[Y]	3.3	3.2	3.3	3.2	22	22
					65	63
	122 cm	120 cm	112 cm	113 cm	116 cm	108 cm

... /2

Table 2. (Continued).

Time of removal (days)	Barley Absent		Barley Present			
	Tobin	Westar	Tobin	Westar	Barley in Tobin	Barley in Westar
56	4.1	3.3	4.1	3.3, 3.4	22	22
					71	71
	124 cm	132 cm	126 cm	129 cm	122 cm	117 cm
	(1985: Tobin, some plants still flowering; Westar, full flower; barley, headed out)					

Number	Canola growth stage description	Number	Barley growth stage description
1.0	Emergence and cotyledon expansion	10 to 19	Number of true leaves unfolded
1.1 to 1.9	First true leaf to all true leaves formed	20 to 29	Number of tillers on the main shoot
2.1	Terminal bud enlarging	31 to 36	Stem elongation, number of detectable nodes
2.2	Bud raised above rosette level	43	Booting, boots just visibly swollen
2.3	Pedicels elongating	54	Inflorescence emergence, head 1/2 emerged
2.4	Buds yellowing	56	Inflorescence emergence, head 3/4 emerged
3.0	First flowers opening on terminal bud	63	Anthesis, beginning of anthesis
3.1	Peduncle elongating, many flowers open	65	Anthesis, anthesis half-way
3.2	Lower pods elongating	71	Milk development, Caryopsis water ripe
3.3	Lower pods starting to fill		
3.4	Seeds enlarging, all buds open		
4.1	Seeds in lower pods, green, opaque		

† General observations were made in 1985, specific growth stages were recorded in 1986 on 10 plants per treatment. Growth stages from Berkenkamp, 1973 (canola) and Zadoks *et al.* 1974 (barley).

§ L, leaves; T, tillers.

Y No plants removed at this time in the experiments.

the reduction in spring growth translate into reduced rapeseed/canola seed yield which led him to conclude that there was little evidence, even with high weed densities, that early removal was necessary for maximum yield. The difference in yield loss between the 'spring' and 'winter' situations is likely due to the growth habits of the species involved. Winter rapeseed/canola grown in Britain has been shown to produce total above-ground biological yields of 490 g/m^2 before the onset of winter and to have total green area indices of 3.5 to 4.0 while still in the rosette stage (Daniels *et al.* 1986). This type of growth habit would make the winter rapeseed/canola crop more competitive with a winter-type barley that is more prostrate during early growth stages than spring barley.

The two cultivars also showed characteristics that were to be expected in *B. campestris* and *B. napus* canola cultivars. Tobin (*B. campestris*) was shorter (16 cm) than Westar (*B. napus*) with more pods (22) per plant and seeds (122/plant) but fewer (3) and smaller seeds per pod. Tobin generally has more branches than Westar. However, the total number of branches of the two canola cultivars did not differ in this experiment (Table 3).

There was some indication of compensation between yield components in this experiment. The seeds of canola plants on weedy control plots were larger than the seeds produced by plants that were weed-free or had barley left in them up to 42 days after planting (Figure 2). This indicated that between 42 days after planting and harvest, the barley plants limited canola seed yield by limiting sink formation (*i.e.*, pods, seeds). Even if barley was left in the crop up to 42 days after planting, the plants still had the potential to produce enough pods and seeds for high yield.

The effect of time of barley removal on the components of canola yield (branching, pods, seeds, seeds per pod, 1000-seed weight) was minimal. The duration of barley competition did not change the overall number of branches produced per canola plant (Table 3). There were more primary branches produced in the weed-free canola than in the weedy check. However, the primary branch counts in the barley removal treatments did not differ. A similar response occurred with the number of pods per plant and seeds per plant . There was a of a reduction in pod and seed number as the time of barley removal was delayed, but the actual number of pods and seeds did not differ significantly between the different removal times. The time barley remained in the canola crop did not affect the number of seeds per pod or the 1000-seed weight on a per plant basis (Table 3).

Table 3. Mean plant height, total branches, primary branches, pods, seeds, seeds/pod and 1000-seed weight of canola subsample plants taken at harvest, combined over years[†].

Treatment		Plant height (cm)	Total branches (#/plant)	Primary branches (#/plant)	Pods (#/plant)	Seeds (#/plant)	Seeds/ pod (#)	1000-seed weight (g)
Year	1985	69 b[§]	3.2 b	2.6 b	45 b	612 b	15 a	2.97 a
	1986	126 a	6.0 a	4.0 a	77 a	1064 a	15 a	2.47 b
Cultivar	Tobin	89 b	4.6 a	3.3 a	71 a	871 a	13 b	2.48 b
	Westar	105 a	4.3 a	3.2 a	49 b	749 b	16 a	2.97 a
Duration	0	101 a	4.8 a	3.5 a	70 a	970 a	15 a	2.76 a
	7	98 a	4.3 a	3.2 ab	60 ab	843 ab	15 a	2.66 a
	14	100 a	4.6 a	3.3 ab	60 ab	794 ab	14 a	2.52 a
	21	97 a	4.9 a	3.3 ab	62 ab	832 ab	14 a	2.74 a
	28	97 a	4.9 a	3.5 a	63 ab	867 ab	14 a	2.50 a
	35	95 a	5.1 a	3.6 a	63 ab	869 ab	15 a	2.85 a
	42	95 a	4.2 a	3.2 ab	53 ab	720 ab	15 a	2.84 a
	56	97 a	4.0 a	3.0 a	57 ab	774 ab	15 a	2.84 a
	WDCK[Y]	96 a	3.4 a	2.5 b	46 b	600 b	12 a	2.78 a

[†] Total branches, primary branches, pods/plant and seeds/plant means are detransformed. A $\log_{10}(x+1)$ transformation was required to normalize the data.

[§] Means within column groups followed by the same letter are not significantly different according to Student-Newman-Keul's test, $P \leq 0.05$.

[Y] WDCK, barley left in the crop until harvest.

The differences observed between the years exhibited the type of compensation that would be expected to occur in canola. In 1985, the plants were small in stature (69 cm) with few branches (3/plant), pods (45/plant) and seeds (612/plant). However the 1000-seed weight was high (2.97 g). In 1986, the plants were taller (126 cm), with more branches (6/plant), pods (77/plant) and seeds (1064/plant). The individual seeds were not filled as well as they were in 1985, and consequently the 1000-seed weight was only 2.47 g. The number of seeds per pod remained a constant 15 in both years (Table 3).

SUMMARY

Competition between barley and canola began when the canola rosette had only two to three true leaves. Tobin (*B. campestris*) and Westar (*B. napus*) canola responded to the length of time of barley competition in the same manner and both cultivars had similar seed yields. Canola seed yield was already reduced by 10% when barley was permitted to remain in the crop for 14 days after plant emergence. While barley remained in the canola crop, seed yield continued to decline. The overall reduction in stem dry matter, which was proportional to the time barley remained in the crop, was largely responsible for the reduced canola seed yield. The number of pods per plant and seeds per plant recorded at harvest also declined in proportion to the time that barley was present in the canola. Yield losses incurred by not removing barley from a canola crop at Lacombe were larger than those reported in the literature to date.

GENERAL DISCUSSION

The degree of competition encountered by individual canola and barley plants in these experiments was a result of many factors modified by the soil and climatic conditions encountered at Lacombe. The response of canola to increased intra- or inter-crop competition did not vary between the experiments. Invariably, the response to increasing plant density was a plastic one. Individual plants did not die, rather they grew less. The reduction in dry matter production resulted in less branching; fewer pods were maintained until harvest time. In some instances, seeds per pod and seed filling were affected. Because of the indeterminate growth habit of rapeseed/canola, the crop had a greater opportunity to recover from the effects of competition than barley.

The number of spike-bearing tillers remaining at harvest was critical to barley yield. Barley was sensitive to the effects of plant competition at the time of tiller initiation. The determinate nature of the species made it difficult for the barley to compensate for the reduction in culms due to plant competition. The number of seeds per spike and seed size were much more limiting than seeds per pod and seed size in canola, simply because the canola plants had the potential to produce more branches and pods over a wider time period than barley had the opportunity to produce tillers.

The difference in growth habits of the two species reflected in the results obtained in experiments that were conducted. The results in Chapter 1 show that *Brassica* cultivars/lines that had a high yield potential under weed-free conditions also had higher yields when barley was present. Plants which were the first to flower, had a high dry matter production, and partitioned a high proportion of dry matter into grain, were the most successful under weedy and weed-free conditions.

The basic growth pattern of *Brassica* was varied with crop genotype and the climatic conditions that occurred at Lacombe. Of the two *Brassica* types which are commonly grown in the Lacombe area, Tobin (*B. campestris*) out-yielded Westar (*B. napus*). This was no doubt due to the relatively short growing season at this location. There were several dry periods during the summers of 1985 and 1986. This, in part, could explain the excellent yields achieved by the two *B. juncea* varieties which are known to be more tolerant of drought. Under weed-free conditions they out-yielded Tobin by 22% and were also highly competitive with the barley. Hybrid canola, which has been highly touted for its vigour, did not produce plants that were any more competitive with barley than the other material in the test. Theoretically, the plants had the genetic potential to be high-yielding (at least in pure stands), but the climate at the location they were grown was perhaps limiting.

How can a producer take advantage of the 'biological powers' of a *Brassica* crop genotype? Selection of a crop variety can be the first step in an effective weed control programme. The results from Chapter 1 suggest that when fields have the potential to be weedy it would be wise to seed the best adapted, highest yielding *Brassica* cultivar available.

In the time of emergence test (Chapter 4), Tobin (*B. campestris*) was observed to develop at a faster rate than Westar (*B. napus*). By examining the barley development, it was evident that Tobin reduced barley growth early in the season, while Westar was more competitive later in the season. This has ramifications for a producer selecting canola cultivars. If they have the option to use either Tobin or Westar, they could utilize Tobin if they expect early developing weeds like stinkweed (*Thlaspi arvense* L.) in a field, and seed Westar in a field where late emerging weeds like Canada thistle (*Circium arvense* (L.) Scop.) predominate.

High planting rates have been recommended as a method of cultural weed control for many years, but does it work for canola? The experiment described in Chapter 2 was designed to answer this question. Under weed-free conditions, the highest yields of Tobin (*B. campestris*) and Westar (*B.napus*) were at the lowest seeding rates (approximately 1 kg/ha). As plant density increased, plant competition increased and the canola plants became proportionally smaller. Per plant, they had lower shoot weights, seed yields, branch numbers, pod numbers and frequently lower seed weights. There was more intra-specific plant competition between plants in mono-cropped Westar than Tobin. The response of the canola plants to the addition of barley was similar to that of increasing plant density in pure stands. At the lowest canola densities, the barley alone was likely responsible for the reduced branch and pod numbers that were observed, but as the total population density increased both intra- and inter-specific competition were operative. More inter-specific competition occurred between Tobin and barley than Westar and barley. The cultivar of choice for a producer anticipating volunteer barley in a field would be Tobin.

No ideal seeding rate for Tobin or Westar growing with barley could be established. Although the plant densities used in the test fall within the range of rates recommended for central Alberta, had higher plant densities been used, an optimum plant stand for canola growing with barley might have been identified. Since canola seed yield increased as the plant density increased in the experiment, the only recommendation that can be made to farmers using the 'biological powers' of the crop is to establish plant stands above those achieved in the experiment.

What was the result of manipulating competition factors associated with the barley (weed)? When the canola was grown at a set population and the barley density varied (Chapter 3), canola seed yield declined as barley density increased. The response of the canola plants to the competition was characteristically plastic. The reduction in canola seed yield was due to a decrease in plant size and harvest index as the total plant population increased. The time at which barley emerged in a canola crop had a similar effect on canola seed yield (Chapter 4), primarily a reduction in the number of pods maintained until harvest.

Producers have little control over some of the biological factors, such as weed density, weed distribution and time of weed emergence, associated with volunteer barley in canola. They can only manage their crops so that the potential for volunteer barley is reduced. This means that combines must be adjusted properly and grain harvested before it shatters. The one factor that is under producer-control is the amount of time the barley remains in the crop.

The typical producer response to the assault on crop yield by weed competition is to remove the weeds. While this can be done by tillage, more often it means the use of a herbicide. It has generally been stated that plants begin to compete with each other as soon as an essential resource becomes limiting. Competition between a moderate density of barley and canola ~~was obs~~erved when the canola rosette has only two to three leaves (Chapter 5). The response in Tobin (*B. campestris*) and Westar (*B. napus*) was the same. By 14 days after canola and barley emergence, canola seed yield was reduced by 26%, largely because the overall size of the plants had been reduced and they had fewer pods.

There is no doubt that a moderate density of barley in canola will reduce seed yield. However, even when a producer has chemicals available that can be safely sprayed until barley is in the six-leaf stage, it is critical that these herbicides are applied as soon after weed emergence as possible. Herbicide application decisions are usually not based on biology, but on economics (and frequently the weather).

Volunteer crops are 'special case' weeds, as they have economic value. 'To spray or not to spray' that is the question. It is in the development of the economic 'bottom line' that the biological aspects of plant competition (*i.e.* weed density, time of emergence) meet factors that are determined outside the farm gate. Crop commodity prices set by the world market are the critical element in the development of economic thresholds for weed control.

Volunteer barley in canola represents a case where the crop is much more valuable than the weed. A high value crop generally means that a producer can afford higher input costs. Unfortunately, pesticide companies know this as well, and products available for control of weeds in higher value crops are often priced accordingly. Producers must know if they are getting the return in yield on their herbicide investment. The results described in Chapters 3 and 4 suggest that there is a much higher tolerance level for volunteer barley than one might think. It was not economical to control barley with sethoxydim until there were over 50 barley plants/m^2. The time of emergence work suggests that it is worthwhile to remove this density of barley even if it emerged eight days after the crop. Unfortunately, further research is required to provide information on the time of emergence of lower densities of volunteer barley.

To summarize, these experiments have provided some information that can help producers manage their volunteer barley weed problems. Initially they should be selecting the highest yielding, best adapted variety for their region. Seeding the crop at a high rate may help if barley is expected to be a problem, however, the cost of the extra seed must be balanced with the value of the volunteer barley. As canola yield losses are high when barley emerges before the crop, it would be judicious to exchange the seeder for the cultivator if volunteer barley is evident in the field. It appears that the cost of post-emergence herbicides can not be justified when the density of volunteer barley is low. If chemicals are warranted for volunteer barley control, they should be applied as early as possible, preferably within two weeks of plant emergence.

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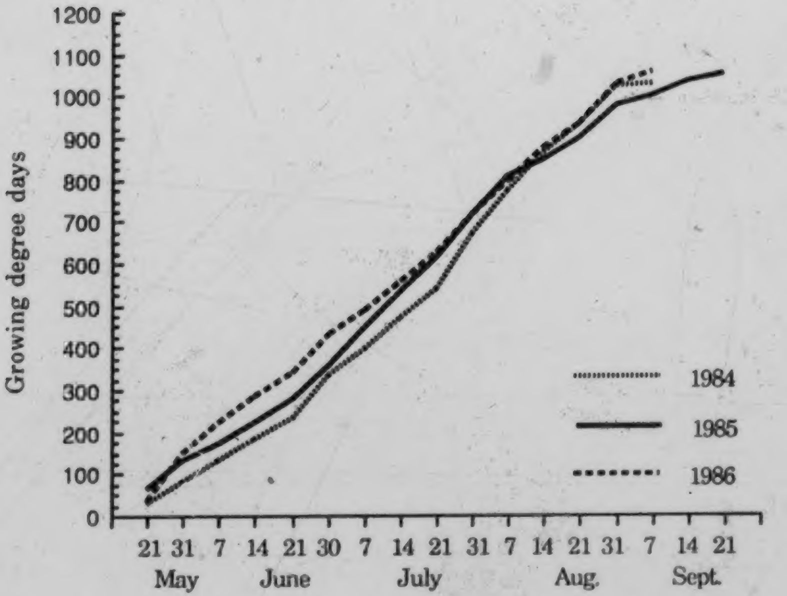
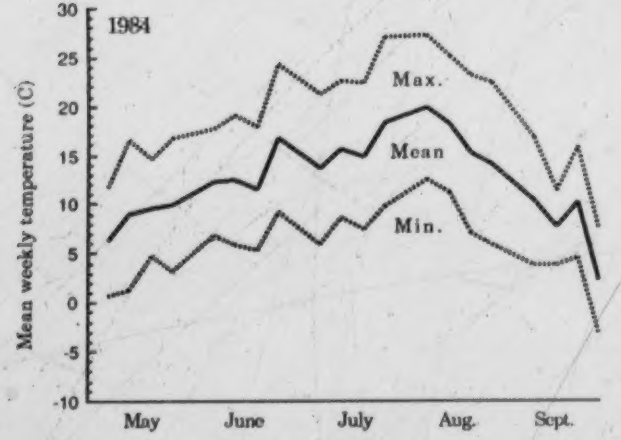
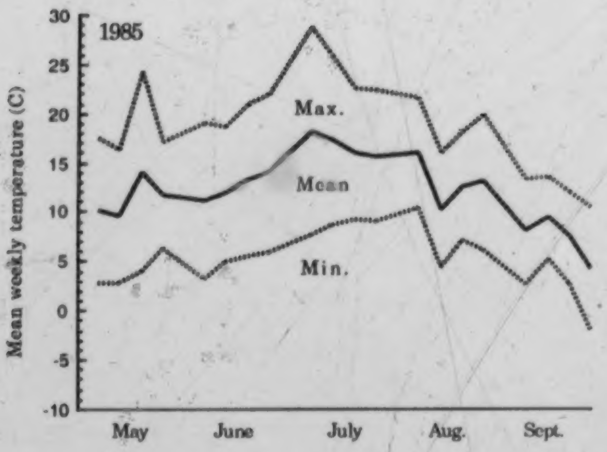
APPENDICES

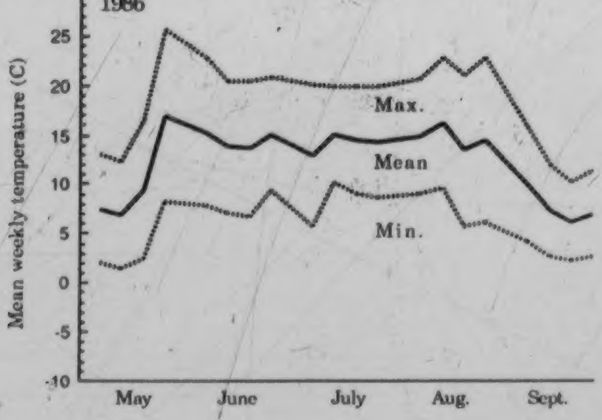
Appendix 1. Growing degree days (base temperature 5 C) at Lacombe, Alberta accumulated from May 15 to frost (-2 C), 1984, 1985 and 1986.


Growing degree days
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
21 31 7 14 21 30 7 14 21 31 7 14 21 31 7 14 21
May
June
July
Aug.
Sept.
1984
1985
1986

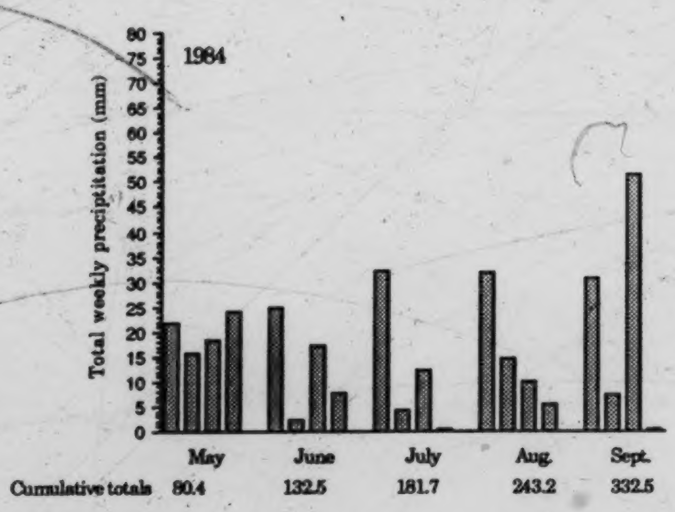
Appendix 2. **Mean weekly temperature at Lacombe, Alberta, May to September, 1984, 1985 and 1986.**

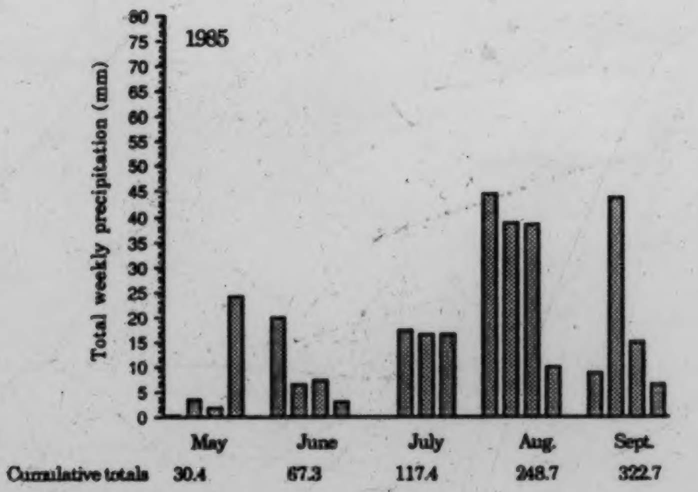

1984
Max.
Mean
Min.
Mean weekly temperature (C)
30
25
20
15
10
5
0
-5
-10
May
June
July
Aug.
Sept.

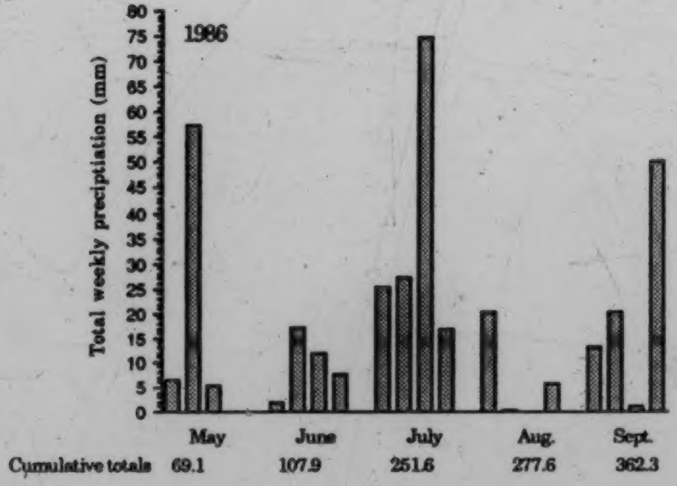

1985
Max.
Mean
Min.
Mean weekly temperature (C)
30
25
20
15
10
5
0
-5
-10
May
June
July
Aug.
Sept.


1986
Max.
Mean
Min.
Mean weekly temperature (C)
30
25
20
15
10
5
0
-5
-10
May
June
July
Aug.
Sept.

Appendix 3. Total weekly precipitation at Lacombe, May to September, 1984, 1985 and 1986.


1984
Total weekly precipitation (mm)
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
May
June
July
Aug.
Sept.
Cumulative totals
80.4
132.5
181.7
243.2
332.5


1985
Total weekly precipitation (mm)
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
May
June
July
Aug.
Sept.
Cumulative totals
30.4
67.3
117.4
248.7
322.7


1986
Total weekly precipitation (mm)
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
May
June
July
Aug.
Sept.
Cumulative totals
69.1
107.9
251.6
277.6
362.3

Appendix 4. Relationship between mean log $_{10}$(canola seed yield g/plant+1) and mean components of canola yield, Chapter 4.

Year	Cultivar	Weed-free check (g/plant)	Regression coefficients[†] *a*	*b*	*c*	*d*	*e*	R^2	Significance[§]
1985	Tobin	4.56	-1.25	0.60 (0.03)[Y]	0.03 (0.002)	0.11 (0.01)	0.08 (0.04)	0.99	**
	Westar	3.50	-0.98	0.43 (0.07)	0.02 (0.003)	0.10 (0.01)	0.18 (0.06)	0.98	**
1986	Tobin	7.59	-1.57	0.77 (0.03)	0.03 (0.002)	0.09 (0.02)	-	0.97	**
	Westar	2.64	-1.14	0.59 (0.03)	0.03 (0.001)	0.09 (0.01)	-	0.97	**

[†] Following the model, $Y = a + b\mathrm{TP} + c\mathrm{SP} + d\mathrm{SW} + e\mathrm{TB}$ where yield is $\log_{10}$(seed yield+1); TP, $\log_{10}$(pods+1) (#); SP, seeds/pod (#); SW, 1000-seed weight (g); TB, $\log_{10}$(total branches+1) (#), n=28.

[§] **, significant at $P \leq 0.01$.

[Y] Standard error bracketed.

Appendix 5. Relationship between mean log $_{10}$(barley seed yield g/plant+1) and mean components of barley yield, Chapter 4.

		Regression coefficients†						
Year	Treatment	*a*	*b*	*c*	*d*	*e*	R^2	Significance§
1985	Barley in Tobin	-0.85	0.11 (0.004)^Y	0.02 (0.003)	0.16 (0.01)	0.05 (0.003)	0.98	**
	Barley in Westar	-0.75	0.13 (0.006)	0.02 (0.005)	0.11 (0.02)	0.05 (0.01)	0.97	**
1986	Barley in Tobin	-0.78	0.09 (0.003)	0.02 (0.003)	0.13 (0.02)	0.06 (0.006)	0.99	**
	Barley in Westar	-0.76	0.08 (0.03)	0.02 (0.003)	0.015 (0.02)	0.06 (0.005)	0.99	**

† Following the model, $Y = a + bSP + cNS + dSN + eKW$ where yield is log$_{10}$(seed yield+1); SP, spikes/plant (#); NS, nodes/spike (#); SN, seeds/node (#); KW, 250-kernel weight (g), n=28.

§ **, significant at $P \le 0.01$.

Y Standard error bracketed.